University of Alberta

RELATIONSHIPS BETWEEN CHICK TRAITS AND BROILER BREEDER REPRODUCTIVE COMPETENCE

by

NICHOLAS JOHN WOLANSKI

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

in Animal Science

Department of Agricultural, Food and Nutritional Science

Edmonton, Alberta

Fall 2007

Library and Archives Canada

Published Heritage Branch

395 Wellington Street
Ottawa ON K1A 0N4
Canada

Bibliothèque et Archives Canada

Direction du Patrimoine de l'édition

395, rue Wellington
Ottawa ON K1A 0N4
Canada

Your file Votre référence
ISBN: 978-0-494-33373-0
Our file Notre référence
ISBN: 978-0-494-33373-0

NOTICE:
The author has granted a non-exclusive license allowing Library and Archives Canada to reproduce, publish, archive, preserve, conserve, communicate to the public by telecommunication or on the Internet, loan, distribute and sell theses worldwide, for commercial or non-commercial purposes, in microform, paper, electronic and/or any other formats.

The author retains copyright ownership and moral rights in this thesis. Neither the thesis nor substantial extracts from it may be printed or otherwise reproduced without the author's permission.

AVIS:
L'auteur a accordé une licence non exclusive permettant à la Bibliothèque et Archives Canada de reproduire, publier, archiver, sauvegarder, conserver, transmettre au public par télécommunication ou par l'Internet, prêter, distribuer et vendre des thèses partout dans le monde, à des fins commerciales ou autres, sur support microforme, papier, électronique et/ou autres formats.

L'auteur conserve la propriété du droit d'auteur et des droits moraux qui protège cette thèse. Ni la thèse ni des extraits substantiels de celle-ci ne doivent être imprimés ou autrement reproduits sans son autorisation.

In compliance with the Canadian Privacy Act some supporting forms may have been removed from this thesis.

While these forms may be included in the document page count, their removal does not represent any loss of content from the thesis.

Conformément à la loi canadienne sur la protection de la vie privée, quelques formulaires secondaires ont été enlevés de cette thèse.

Bien que ces formulaires aient inclus dans la pagination, il n'y aura aucun contenu manquant.

Canada

ABSTRACT

The goal of a hatching egg producer is to ship fertile eggs that hatch well with a high percentage of saleable chicks. In the industry there exists considerable variation in chick quality between producers and hatcheries.

Variation in chick hatch weight was lower than the variation in chick residual yolk mass. Measuring chick abdomen height and consistency were useful in quantifying yolk reserves. Additionally, growth characteristics of commercial broiler breeder flocks were evaluated through to 61 wk. In the male flock mortality and culling represented nearly 40 %. Further research should look into this mortality with the objectives of defining the behavioral basis for these losses. Approximately 20 % of hens had a reproductive disorder or ceased egg production by 61 wk. An oviduct eversion test enabled the prediction of laying status in hens. Information on chick quality and breeder reproductive competence allows producers to make better management decisions.

ACKNOWLEDGEMENTS

The financial support of this thesis was provided by many different organizations. I would like to thank the Canadian Broiler Hatching Egg Marketing Agency, Pacific Egg and Poultry Association, Alberta Agriculture Research Institute for their financial support. Industry support in the form of in-kind donations of hatching eggs and technical advice was provided by Aviagen North America and Lilydale Foods.

The first day I ever met Dr. Frank Robinson I knew that he would play a profound role in shaping my life. Throughout my undergraduate degree Frank provided me with opportunities and also supported me when I was unsure of myself. It was thanks to him that I experienced my first ever plane ride and my first ever time pipetting semen from a turkey tom. Frank has been a constant source of inspiration in my life. Each day I view the effort and knowledge he brings to our poultry group and I aspire to gain half as much respect as he has earned in the poultry industry. I have no doubt that without Frank's care and supervision I would not have embarked on doing a masters degree. Thank you so very much for challenging me and I hope you are proud.

Everyone at the University of Alberta Poultry Research Center was instrumental in allowing me to complete this research. In addition to technical support I share a special personal bond with everyone at the Poultry Unit. Felicity Dennis is definitely my mother at the poultry unit and she always made sure that I was properly fed. Kerry Nadeau is the second sister that I always wanted; her and I could always find something to laugh at. Lyle Bouvier is that strange uncle who hums songs like "You can't roller skate in a buffalo crowd" that always make you laugh. On a more serious note I had valuable advice on experimental design and statistical analysis from Rob Renema, Luis

Romero, and Martin Zuidhof. I would like to thank all of the summer students and my fellow graduate students that assisted in my projects. I know that I can not list everyone that was essential to the completion of this thesis but I promise you that I will write another thesis listing all that everyone has contributed. A final thank you to everyone who taught me about life apart from chickens in the last 3 years, because I have grown and developed as a person.

I would like to thank both my friends and family that have endured me talking about chickens and turkeys. I hope that you have learned something and want to hear more because I plan to keep talking. My friends Corey, Waleed, Ali, Marek, Arran, Eurt, have all shaped my life and allowed me to open my mind to possibilities that exist. My parents Linda and Gary have been a source of motivation for me beyond explanation. My siblings Ken, Michelle, and Christopher have been part of me during my early mornings and late nights. Thank you to my devoted girlfriend Pamela Gottselig who has taught me how to truly live life and how to enjoy the simple things. I wish to thank everyone for all of their assistance, and patience while I have been completing my M Sc. Program.

TABLE OF CONTENTS

1.0 LITERATURE REVIEW

1.1 INTRODUCTION 1

1.2 STRUCTURE OF AVIAN HATCHING EGGS 1

1.2.1 Constituents of an Egg 2

1.2.2 Egg Size 4

1.2.3 Embryonic Development 4

1.2.4 Hatching Process and Yolk Absorption 6

1.3 CHICK QUALITY 7

1.3.1 Residual Yolk at Hatch 8

1.3.2 Early Growth of Breeder Chicks 9

1.4 GROWTH AND SEXUAL DEVELOPMENT IN THE HEN 10

1.4.1 Pullet Growth 11

1.4.2 Onset of Lay 13

1.4.3 Ovary 14

1.4.4 Oviduct 15

1.4.5 Egg Production and Fertility 16

1.5 GROWTH AND SEXUAL DEVELOPMENT IN THE ROOSTER 16

1.5.1 Cockerel Growth 17

1.5.2 Onset of Semen Production 18

1.5.4 Fertility and Body Weight 19

1.6 CONCLUSIONS 20

1.7 DESCRIPTION OF EXPERIMENTS 21

1.8 LITERATURE CITED 23

2.0 RELATIONSHIP AMONG EGG CHARACTERISTICS, CHICK MEASUREMENTS, AND EARLY GROWTH TRAITS IN TEN BOILER BREEDER STRAINS

2.1 INTRODUCTION 37

2.2 MATERIALS AND METHODS 38

2.2.1 Eggs for Egg Quality 39

2.2.2 Eggs for Conductance 39

2.2.3 Egg for Incubation 40

2.2.4 Statistical Analysis 41

2.3 RESULTS AND DISCUSSION 41

2.3.1 Egg Quality Characteristics 41

2.3.2 Eggshell Conductance 43

2.3.3 Egg Weight and Characteristics of Incubated Eggs 43

2.3.4 Hatch Weight Relative to Egg Weight 44

2.3.5 Residual Yolk and Albumen 45

2.3.6 14 d Growth Data 46

2.3.7 14 d Dissection Data 47

2.3.8 Correlations and Coefficients of Variation 49

2.4 REFERENCES 51

3.0 RELATIONSHIP BETWEEN CHICK CONFORMATION AND QUALITYMEASURES WITH EARLY GROWTH TRAITS IN MALES OF EIGHT SELECTED, PURE, OR COMMERCIAL BROILER BREEDER STRAINS

3.1 INTRODUCTION 65

3.2 MATERIALS AND METHODS 67

3.2.1 Statistical Analysis 68

3.3 RESULTS AND DISCUSSION 69

3.3.1 Chicks at 0 d of Age 69

3.3.2 Processed Chicks at 14 d of Age 73

3.3.3 Correlations 76

3.4 REFERENCES 78

4.0 RELATIONSHIPS AMONG GROWTH, VARIABILITY, AND MORTALITY OF MALE BROILER BREEDERS THROUGH A 61 WEEK PRODUCTION CYCLE

4.1 INTRODUCTION 91

4.2 MATERIALS AND METHODS 92

4.2.1 Statistical Analysis 95

4.3 RESULTS AND DISCUSSION 95

4.3.1 Hatch Traits of Males 95

4.3.2 Frame Size 96

4.3.3 Body Weight and Mortality 98

4.3.4 Breast Muscle and Testes Data 100

4.3.5 Foot Pad and Feather Score 101

4.3.6 Mortality and Culling 101

4.3.7 Correlations 103

4.3.8 Conclusions and Applications 103

4.4 REFERENCES 105

5.0 INDIVIDUAL FEMALE BROILER BREEDER GROWTH, VARIABILITY, AND REPRODUCTIVE PERFORMANCE FROM HATCH TO FLOCK DISPERSAL IN A COMMERCIAL SETTING

5.1 INTRODUCTION 116

5.2 MATERIALS AND METHODS 118

5.2.1 Stocks and Management 118

5.2.2 61 Week Data Collection 119

5.2.3 Statistical Analysis 120

5.3 RESULTS AND DISCUSSION 120

5.3.1 Rearing Data 120

5.3.2 Egg Production 122

5.3.3 Mortality 124

5.3.4 61 Week External Morphometrics and Dissection 124

5.3.5 Birds Sorted by Body Weight 125

5.3.6 Reproductive Condition 126

5.3.7 Correlations 127

5.3.8 Conclusions and Applications 128

5.4 REFERENCES 129

6.0 GENERAL DISCUSSION 143

LIST OF TABLES

TABLE		PAGE
2-1.	Description and the main selection criteria of ten broiler breeder Strains	55
2-2.	Composition of broiler starter diet fed from day 0 to end of trial (14 d)	56
2-3.	Comparison of egg traits and egg components for ten Strains of broiler breeders	57
2-4.	Comparison of egg desiccation results for ten Strains of broiler breeders	58
2-5.	Chick weight and hatching egg measurements of ten broiler breeder strains	59
2-6.	Comparison of hatch weight and internal organ weights from ten broiler breeder strains processed at hatch	60
2-7.	Comparison of growth rate and external morphology for chicks processed at 14 d	61
2-8.	Correlation coefficients for egg weight and egg composition as related to fresh egg weight from the 10 strains pooled	62
2-9.	Correlation coefficients for hatch weight and composition as related to fresh egg weight from the 10 strains pooled	63
2-10.	Range in variability of traits at hatch for the ten strains of broiler breeder chicks	64
3-1.	Description and the main selection criteria for the eight strains of broiler breeders	83
3-2.	Composition of broiler starter diet fed from day 0 to end of trial	84

LIST OF TABLES

TABLE		PAGE
3-3.	Comparison of chick weight, wet carcass weight, wet yolk wet, dry carcass weight, and dry yolk weight and breast muscle mass at hatch for males of eight broiler breeder strains	85
3-4.	Comparison of external measurements at hatch of males from eight broiler breeder strains	86
3-5.	External measurements of male chicks at hatch and at 14 days of age of males from eight broiler breeder strains	87
3-6.	Comparison of hatch weights, 14 day body weights, BW gain, and breast muscle weight of males from eight broiler breeder strains	88
3-7.	Correlation coefficients for early chick growth and carcass parameters of males from eight broiler breeder strains	89
3-8.	Correlation coefficients for total length, shank length and BW at both time of hatch and 14 days of age (keel is only reported at 14 days) from the eight strains pooled	90
4-1.	Descriptive data which shows BW, length measures, and variability of traits from hatch to 18 wk of age for broiler breeder males as compared to the Ross management guide	109
4-2.	Body weight, carcass morphometrics and liveability of males sorted by barn and BW category (at 18 wk) at the time of depopulation (61 wk)	110

LIST OF TABLES

TABLE		PAGE
4-3.	Dissection results and bird feather and foot scores of male broiler breeders at 61 wk of age	111
4-4.	Correlation coefficients (and P-values) of hatch traits and early growth measurements in juvenile male broiler breeders	114
4-5.	Correlation coefficients (and P-values) of 18 wk weight and 61 week traits in male broiler breeders	115
5-1.	Pullet BW and bone growth for two broiler breeder flocks from hatch to 19 wk of age	134
5-2.	Egg production and mortality values for flock 1 and flock 2 with reference to the Ross 308 management guide	135
5-3.	Body weight, carcass morphometrics and reproductive characteristics of broiler breeder hens from two flocks sorted into 3 BW groupings at 61 wk of age	139
5-4.	Reproductive condition of hens from two flocks sorted into 3 BW groupings at 61 wk of age	140
5-5.	Correlation coefficients (and P-values) of hatch traits and early growth measurements in juvenile female broiler breeders	141
5-6.	Correlation coefficients (and P-values) of 19 wk weight and 61 week traits in female broiler breeders	142

LIST OF FIGURES

FIGURE		PAGE
4-1.	Frequency of distribution for testes weight of males sorted by barn at 61 wk (n = 142 for barn 1 and 114 for barn 2).	112
4-2.	Cumulative mortality of males from hatch to 61 wk with the cause of death as determined by post mortem examination.	113
5-1.	Picture on left depicts a hen which failed to evert her oviduct (predicted as out of lay). Picture on right depicts a hen which has everted her oviduct (predicted as in lay).	136
5-2.	Egg production curves of flock 1 and flock 2 as compared to the Ross management guide for a 308 hen.	137
5-3.	Distribution of large yellow follicle (LYF) numbers for hens from Flock 1 (n = 497) and Flock 2 (n = 564).	138

LIST OF ABREVIATIONS

BW	body weight
CV	coefficient of variation
d	day(s)
FSH	follicle stimulating hormone
g	gram(s)
h	hour(s)
HIGH	body weight 15 % above standard target weight
LH	leutinizing hormone
LOW	body weight 15 % below standard target weight
LYF	large yellow follicle
PS	photo-stimulation
SM	sexual Maturity
STD	standard target body weight
wk	week(s)

1.0 LITERATURE REVIEW

1.1 INTRODUCTION

Chick quality can be influenced by several factors starting at the breeder farm and extended into the broiler barn. A saleable chick, as defined by the poultry industry, generally refers to a chick free of deformities, with dry down, an alert appearance, and a vigorous demeanor. However, considerable variations in chick quality exist from different breeder flocks and among various hatcheries. Detrimental effects to chick quality can occur at the hatching egg farms that are likely related to both internal and external egg composition. At the hatchery, incubation and hatching protocols may negatively impact chick quality if machine conditions are not optimal for certain high yielding strains or eggs from older flocks. One difficulty in attempting to maximize chick quality can be that each hatching egg producer, hatchery, and broiler grower have a slightly different view of what a quality chick represents.

The primary breeding companies constantly develop new products to suit the wishes of these separate groups and research into these new strains must be performed. The goal of this thesis was to evaluate chick quality in several strains while also investigating early growth potential of newly developed strains. A second objective was to investigate both male and female sexual development and senescence in hatching egg flocks under a commercial setting.

1.2 STRUCTURE OF AVIAN HATCHING EGGS

Each hatching egg comprises a cuticle, eggshell proper, shell membranes, albumen and yolk which may have a blastoderm (Brake et al., 1997). On the surface of the yolk there is a specialized structure known as a germinal disc, which contains the

maternal genetics of an egg. In the case of a fertilized egg, male spermatozoa penetrate the perivitelline membrane to fertilize the newly ovulated follicle. Throughout the life of a breeder flock the proportion of yolk, albumen, and shell change. The quality and quantity of each of these egg components has implications in the resulting chick quality.

1.2.1 Constituents of an Egg

The albumen is a complex mixture of more than 40 different proteins (Etches, 1996) secreted from the cells lining the oviduct. The albumen and yolk are connected by a chalaziferous layer which encases the yolk and anchors the yolk within the egg. Albumen is essential in positioning the yolk and blastoderm in the center of the egg away from the shell and shell membranes immediately after lay (Brake et al., 1997). Albumen proteins denature with increased duration of storage resulting in a liquefication of albumen which reduces albumen height and viscosity thus allowing for greater gaseous diffusion (Meuer and Baumann, 1988). Eggs are routinely stored on the farm and in the hatchery prior to incubation which has implications on internal egg quality. Jones and Musgrove (2005), found that albumen height decreased from 7.05 to 4.85 mm after 10 wk of egg storage at 4 C. Brake et al., (1997) reported that genetic differences in albumen quality could largely explain the genetic difference in hatchability.

Yolky follicles are arranged in a hierarchy on the hen's single functional ovary. Tiny yolk droplets are synthesized in the liver and then transported through the vascular system and accumulate to form large yellow follicles (LYF; with a diameter larger than 10 mm) (Hocking, 1993). Overfeeding hens results in extra follicles being recruited into the follicular hierarchy which disrupts the normal ovarian function (Yu et al., 1992). These follicles will continue to grow until the ovum breaks through the stigma and

ovulates leaving a post ovulatory follicle on the ovary. The yolk supplies 90% of the caloric needs of the developing embryo while in the egg (Freeman and Vince, 1974). Post-hatch this internalized residual yolk supplies 20% of the protein and 30% of energy needs for 3 d post-hatch (Murakami et al., 1988). Previous selection experiments have been successful in increasing the yolk-to-albumen ratio (Miyoshi and Mitsumoto, 1980) and altering the yolk percentage (Hartmann et al., 2000). Other researchers have also documented that strain and age both impact the yolk-to-albumen ratio (Fletcher et al., 1981; Hussein et al., 1993).

The eggshell is composed of crystalline calcium carbonate (Brake et al., 1997) which is organized into several regions that provide the rigid structure of the eggshell. Each eggshell has approximately 10,000 pores which allow gaseous diffusion between the developing embryo and the external environment. The length and number of pores determine the rate of vapor passage or egg shell conductance of an egg (Ar et al., 1974; Rahn et al., 1979). Shell quality of hatching eggs remains a concern as later in lay hens produce larger eggs and con currently the bird's active absorption of calcium is declining. Research has shown that the breeder age impacts eggshell quality along with internal egg characteristics (Peebles and Brake, 1986; O'Sullivan et al., 1991; Benton and Brake, 1996). Egg specific gravity is one measure of shell quality in eggs. Eggs which have poor specific gravity (<1.080) have inferior shell characteristics and consequently poorer hatchability, lower hatch weight, and increased early mortality of broiler chicks (McDaniel et al., 1979). Bains (1994) also showed that egg size was an important factor that influences both albumen and shell quality in older hens.

1.2.2 Egg Size

Eggs from older breeders are larger and have thinner shells which allows for greater oxygen and carbon dioxide diffusion across this physical barrier (O'Dea et al., 2004). Embryonic and chick weight is strongly influenced by the age of a breeder flock. Suarez et al. (1997) documented significant hen age and genotype effects on both egg weight and chick weight. More recently, Hartmann et al. (2003) suggested that the maternal influence on chick weight was related to egg compositional differences which may be genetic or environmental in origin. A study by Tullett and Burton, (1982) found a strong relationship between egg weight at setting and chick weight. Large egg size, which is common in older breeders, may allow additional room for embryonic development and result in observable differences in chick weight and carcass morphometrics at hatch. Hassan and Nordskog, (1971) showed that late embryonic growth was increased in heavier eggs. The study by Hartmann et al. (2003) concluded that the hen effects on yolk proportion, yolk weight, albumen weight, albumen dry matter have a larger influence on chick weight rather than the genetics of the developing chick.

1.2.3 Embryonic Development

Cell division and embryonic growth begin shortly following fertilization. By the time an egg is laid the fertilized ovum will have undergone division to produce an embryo of 40,000 - 60,000 cells (Ricks et al., 2003). A unique characteristic of hatching eggs is that they are able to be stored in a cool (10-17 C) and humidity (70-80 % RH) controlled environment before incubation. Storage conditions of 12-27 C are within the range of physiological zero (Funk and Biellier, 1944; Decuypere and Michels, 1992) which prevents further cell division and limits weight loss from the egg. Early work on

egg storage showed a beneficial impact of eggs being stored briefly as compared to fresh set eggs in both turkeys (Asmundson and MacIlraith, 1948) and chickens (Funk, 1950). However, egg storage for a prolonged period (14 d) reduced the hatchability of all eggs set by nearly 30 % as compared with eggs which were set after 4 d of storage (Fasenko et al., 2001). The routine storage of eggs causes a decrease in total mass due to evaporative loss through eggshell pores.

Within 24 h of placement in the incubator the embryo establishes three layers of tissue: the ectoderm, endoderm, and mesoderm. These layers will produce all of the organs and tissues of hatchling. Briefly, the ectoderm will differentiate into the respiratory and nervous system. The mesoderm gives rise to the skeletal, muscular, and connective tissues. The endoderm forms a connection with the chick's primary nutrient source the yolk sac. After establishment of the embryonic tissues, a circulatory system begins functioning to provide tissues with nutrients and remove waste products of cellular metabolism. The chicken embryo develops over a 21 d incubation period which can be divided into early (1-7 d), middle (8-14 d) and late (15-21 d) embryonic stages.

In the first 7 d of incubation, the rate of cell division and multiplication is phenomenal. It is during this stage that problems with egg storage or shell quality can manifest themselves in a high percentage of early dead embryos. With the rapid growth of embryonic tissues the need for proper gas exchange is apparent. The chorioallantoic membrane creates a greater surface area for gas exchange and permits rapid embryonic growth. Turning of hatching eggs during the first wk of incubation has been described as vital for proper membrane formation and hatchability (Déeming, 1989; Tona et al., 2005; Elibol and Brake, 2006).

The middle phase of development is denoted by the appearance of the embryonic eye. Problems with shell quality may result in bacterial contamination of the hatching eggs causing the death of the embryo. Also, during this phase of incubation, nutritional deficiencies in the parents can cause embryonic death but, in general mortality during the 8-14 d period is low.

On day 18, eggs are transferred from the incubators to the hatchers with the assistance of candling machines. Eggs which are infertile or early dead are removed to allow more room in the hatching baskets for chicks. In the final 2 d of incubation a chick shifts from passive diffusion of oxygen through the chorioallantois to active pulmonary respiration. The moment when a chick breaks through the internal membranes of the egg is known as internal pipping. The majority of embryonic losses in the late developmental period are due to extended pipping and/or problems which prevent chicks from clearing the shells. Embryonic mortality in broilers has been reported to affect 8 % of fertile hatching eggs (Quemeneur et al., 1989). In the late embryonic stage of development, the percentage of mortality is often high (3.0-4.5 %). Increases in embryonic mortality are a significant cause for decreased hatchability in fertile eggs from older breeders (Tona et al., 2001). When eggs are incubated under artificial conditions, approximately 12 % of egg weight must be lost at the time of internal pipping (Tullett, 1981; Peebles and Brake, 1986).

1.2.4 Hatching Process and Yolk Absorption

By the 2nd d of incubation a primitive yolk stalk develops which connects the developing embryo to the yolk. Also early in incubation the embryo extends the yolk sac membrane around the yolk; this encases the yolk and creates a vascular connection

between the embryo and the yolk. During late incubation, yolk contents are absorbed directly by the blood via the yolk sac membrane (Lambson, 1970) and into the digestive system via the yolk stalk (Esteban et al., 1991; Noy et al., 1996). Through the oxidation of fats from the yolk, a chicken embryo derives more than 80 % of the total energy required prior to hatch (Romanoff and Romanoff, 1967). On the nineteenth day of incubation, the chick begins to internalize the remaining yolk sac through the navel which has not yet fully closed. Residual yolk serves a transitional role as the chick's metabolism shifts from lipid utilization to carbohydrate metabolism and absorption (Noy and Sklan, 2001). At hatch, residual yolk must be completely enclosed inside the bird's body or problems with unhealed navels and omphalitis result in compromised chick quality. Chicks from older breeders have larger residual yolk at hatch due to larger yolk size in older breeder eggs (Vieira and Moran, 1998). In a report by Wolanski et al. (2004a) the range in residual yolk was found to be 0.8 g to 10.6 g in chicks from the same hatch. Nobel and Moore (1964) quantified that a fertile hatching egg contains 6 g of lipid with 5 g of this energy being utilized by the developing embryo. A study by Ding and Lilburn (1996) showed that yolk sac lipids and fatty acids are rapidly utilized during the later stages of incubation.

1.3 CHICK QUALITY

Hatch weight is highly correlated with egg weight at setting (McNaughton et al., 1978; Proudfoot et al., 1982; Burke, 1992). Current research by Tona et al. (2004) has demonstrated that chicks of higher quality had improved growth. Within the poultry industry, there is no objective measure of chick quality that is universally accepted. Hatch weight has been commonly used as an index of quality however; this measure also

includes residual yolk reserves of a chick which may skew the assessment of chick quality. Residual yolk reserves can be extremely variable from bird to bird and from one strain to another. Research at the University of Alberta has investigated the potential of using a manual palpation of the abdomen in freshly hatched chicks to estimate residual yolk content in a nondestructive manner. Similar scoring systems have been developed to subjectively evaluate chick traits at hatch (Cervantes, 1993; Tona et al 2003). However, all of these systems have a subjective component and measure different traits but, each scoring system evaluated abdomen condition and residual yolk content. There is increasing interest of using chick length and the length of other physical traits at hatch as indices for embryonic development and chick quality (Yalçin and Siegel, 2003).

1.3.1 Residual Yolk at Hatch

The poultry industry in North America is heavily concentrated in the southern United States, therefore, chicks are hatched and processed and then transported to other states or even to Canada. Therefore a chick may not have access to feed for 36 – 48 h after hatching which results in a loss of BW (Noy and Sklan, 1998; Noy and Sklan, 1999). During this period of feed deprivation, the chick must utilize internalized yolk sac contents to maintain body tissues. The transition from lipid-rich yolk utilization to digestion of carbohydrate and protein-rich feeds facilitates rapid development of the gastrointestinal tract in hatchlings (Uni et al., 1999). Peebles et al. (2001a) postulated that chicks with increased yolk absorption would have enhanced survivability and improved body weight gain. Furthermore, Noble et al. (1986) reported that high first week mortality in broilers was associated with reduced lipid mobilization of chicks from very young breeder hens. Absorption of residual yolk is essential for the initiation of

growth in domestic poultry (Chamblee et al., 1992). Murakami et al. (1992) illustrated that residual yolk plays a pivotal role in the initiation of growth because, there was a 2 d delay in growth of duectomized chicks compared to sham operated and control chicks. Residual yolk typically constitutes 10 % of a chicks hatch weight (Peebles et al., 2001b) and, supplies 50 % of the energy requirements the first day post-hatch (Latour et al., 1994). By 11 d of age residual yolk is negligible in size and remains attached at the Meckel's diverticulum (Nitsan et al., 1995).

1.3.2 Early Growth of Breeder Chicks

The sex of embryos is determined by the presence or absence of the W chromosome. Gender determination is possible at 10 d of incubation by visual examination of the gonads at necropsy. At hatch, there are few breeds of poultry which have secondary sexual characteristics that can be used to identify males from females. Therefore trained individuals known as sexors evert the cloaca of the bird and based on slight anatomical differences the sex of the bird is determined. Since males and females have vastly different growth profiles and feed efficiencies, sex separate rearing may be practiced. Intensive genetic selection by primary breeders has resulted in broiler genotypes with improved growth rates, and broilers are now reaching market weight in fewer days on less feed (Havenstein et al., 1994). May and Lott (2001) found that the maximum rate of gain for broiler males and females were 98 and 83 g/d respectively. Research on broilers by Marks (1985) showed that male and female BW diverged immediately post-hatch with the males having a 7 % advantage in BW as earlier as 14 d post-hatch. In the case of broiler breeders, sex separate rearing is the norm. By feeding

males and females separately producers are better able to manage the BW of both cockerels and pullets during the rearing and lay periods.

1.4 GROWTH AND SEXUAL DEVELOPMENT IN THE HEN

At the time of hatch a pullet will possess all of the follicles necessary for future egg production. The growth of pullet body reserves can be observed by monitoring the BW, fleshing, and development of secondary sexual characteristics. The internal hormonal balance of the bird is not visually apparent, yet understanding the maturation of the regulation of the sex hormones may allow for better prediction of body composition thus enabling producers to make better management decisions to maintain optimum production (Sun et al., 2006). Prior to photo-stimulation (PS) pullets should achieve an appropriate BW and body condition so that they are able to respond to an increase in photoperiod.

Throughout rearing pullets are feed restricted because they lack the ability to self regulate feed intake at a level which allows for optimal future reproduction (Renema and Robinson, 2004). Broiler breeder pullets are commonly PS at 23 wk of age with the onset of egg production following by 2 wk. In an experiment by Robinson et al. (1991) breeder hens were reared to achieve a low BW by 21 wk (1539 g) compared to hens which achieved a high BW (2446 g). The differences in BW observed at 21 wk were also apparent at the time of flock dispersal (62 wk).

During lay, there is constant recruitment of follicles into the LYF hierarchy and eventual ovulation of these large yolky follicles. Yu et al. (1992) reported that 7 – 8 LYF were present on the ovary of feed-restricted hens whereas the full-fed counter parts had 12 LYF. At the time of sexual maturity the optimum number of LYF is between 6-8 LYF

(Gilbert, 1971) and at the end of lay the number decreases to (4 or 5 LYF) (Renema et al., 2001). Robinson et al. (1995) showed that one extra LYF at sexual maturity resulted in a 10 egg decrease in total egg production to 64 wk, due to an increased incidence of soft-shelled and defective eggs. Toward the end of lay, birds will have shorter sequences (Robinson et al., 1990), deposit fat reserves (Sun and Coon, 2005), and mate less frequently (Wilson et al., 1979) necessitating the dispersal of the breeding flock.

1.4.1 Pullet Growth

At hatch, breeder chicks are processed and sexed at the hatchery prior to shipment to a broiler breeder farm. Initially chicks are provided with 23 h of light this ensures that chicks obtain feed and water allowing the birds to start off well. As the birds mature, they are reared on short days 8 L and 16 D with low light intensity during the remainder of the rearing phase. Since female broiler breeders have excellent genetic potential for growth, feed restriction is employed to limit body weight gains, reduce the incidence of obesity, and improve egg production (Hocking et al., 1994; Bruggeman et al., 1999). It has been recognized for over 30 years that there is a negative relationship between growth and reproductive fitness in chickens (Maloney et al., 1967; Jaap and Muir, 1968). The routine feed restriction of broiler breeders from an early age is considered essential for the well-being of the bird. The broiler breeder will become obese and metabolic problems such as fatty liver hemorrhagic syndrome or ascites may result from the over consumption of feed (Leveille et al., 1975).

Feed restriction programs have been found to improve egg production (Yu et al., 1992), increase liveability (Hocking, 1993), and have both positive and negative effects on bird welfare (Zuidhof et al., 1995). Research on feed restriction has focused on the 7-

15 wk period because during this phase pullets are most severely restricted (MacLeod and Hocking, 1993). Bruggeman et al. (1999) has demonstrated that restriction during 7-15 wk had the greatest improvement on reproductive performance. It was suggested that the ovary and hypothalamus of the bird are developing concurrently at this age and if birds receive excess nutrients more LYF are recruited. This leads to multiple hierarchies which results in increased double yolked or defective eggs. Research by Jaap and Muir (1968) and van Middlekoop (1971) documented this phenomenon. These researchers named this problem "erratic oviposition and defective egg syndrome (EODES)". With the increased selection for growth that has occurred in the subsequent 35 years the need to effectively manage and properly allocate feed to breeders is paramount. With over-supply of feed, birds may allocate energy to form extra follicles on the ovary, increase hepatic lipid, and increase abdominal fat deposition. Research by McGovern et al. (1997) showed that the effects of over-feeding are less severe as birds age. Conversely, under-supply of nutrients resulted in a delay of sexual maturity which can compromise egg output. In 1994 broiler breeders, which ranged 10 % above target weight or 10 % below target weight did not negatively affect laying performance (Bartov et al., 1994). However, the reproductive performance of current hens might be compromised if rapid changes in BW do occur.

Severe feed restriction represents a serious animal welfare issue. Breeder diet dilution has been employed to extend feeding time by increasing the total feed volume available to the birds. Hocking et al. (2004) used sugar beet pulp in diets and found it increased feeding time while also modifying bird behaviour. In an earlier study (Zuidhof et al., 1995), oat hulls were found to positively impact a bird's behaviour which is one

measure of bird welfare. A study by Bruggeman et al. (1999) found that diet dilution was successful in extending the feeding time to as much as 10 h when the birds were 30 wk old. This increased access to feed would have beneficial effects on ensuring that birds can obtain a level of gut fill while also improving flock uniformity. Feed-restricted birds are not free from hunger, however, the welfare benefit of reduced incidence of metabolic disorders and lower mortality may outweigh the negative aspects of limit feeding (Whitehead, 2002).

1.4.2 Onset of Lay

The growth of every animal occurs in a highly organized sequence of events that are closely regulated by neoroendocrine, genetic, and environmental components. Birds which have obtained sufficient body stores will become reproductively mature following exposure to an increasing photoperiod. This increase in day length is recognized by hypothalamic photoreceptors in the brain and results in rapid growth of the bird's left ovary and oviduct. The hypothalamic-pituitary-ovarian-axis creates a link between the brain and gonads in birds. The hypothalamus releases ganadotrophin releasing hormone (GnRH) which stimulates the pituitary to release gonadotrophin hormone (i.e. luteinizing hormone (LH)).

A hen is considered sexually mature once she lays her first egg. Eggs laid on consecutive days are termed a bird's sequence length. On days when a hen fails to produce an egg, the day is termed a pause day. Typically toward the end of lay, a hen has shorter sequences and a greater number of pause days. Lower egg production rates with increasing age of hens has been associated with a reduction in follicular maturation (Johnson et al., 1986), an increase in follicular atresia (Palmer and Bahr, 1992), and

decreased sensitivity to neural stimuli responsible for GnRH release (Williams and Sharp, 1978).

1.4.3 Ovary

The structure of a hen's ovary is quite complex and the site of numerous hormonal events. The theca and granulosa cells of the ovary respond to LH by producing androgens, progesterone, and estrogens which cause sexual maturation. Gonadotrophin hormone also causes an increase in the basal levels of follicle stimulating hormone (FSH) which acts on the pool of small yellow follicles causing a certain number to grow in diameter. The theca tissues, which surround the growing LYF, are highly vascularized to assist with the transfer of very low density lipoproteins (VLDL), synthesized in the liver, and these yolk droplets are deposited in ring like formations within the yolky follicles. In an experiment by Yu et al. (1992) birds were fed dye capsules with alternating colours every other day. The resulting yolk from eggs produced by these hens had a rainbow appearance when viewed after cross sectioning the hard boiled yolk. These LYF grow and are ovulated from the ovary triggered by a surge in LH. In cases where hens are overfed, ovarian follicular development may commence as early as 14 wk of age even in the absence of a photo-stimulatory signal (Hocking et al., 1994). Hocking (1993) has documented an increase in follicular atresia of overweight hens with the level of atresia being positively correlated to BW at sexual maturity. Therefore, hens are feed restricted to delay sexual maturity until adequate body reserves and physiological maturity has occurred. In the industry, there has been a trend toward earlier lighting of broiler breeders, however research has shown this practice can have negative impacts on total

egg production, number of salable chicks produced, and reproductive longevity of hens (McDaniel et al., 1981; Leeson and Summers, 1983; Hocking 1993).

With slower growth profiles, control of the photoperiod, and feed restriction, it is possible to delay sexual maturity. Various trials (Pym and Dillon, 1974; Robinson et al., 1986; Yu et al., 1992) have demonstrated that feed-restricted birds come into lay later than full-fed counterparts. Robinson et al. (1993) reported that when hens are photo-stimulated at 18 or 20 wk of age there is only a minor delay in sexual maturity with feed restriction programs.

1.4.4 Oviduct

The oviduct serves a vital function in the synthesis and oviposition of eggs. In some cases follicles will ovulate and the infundibulum fails to engulf the follicle which results in a condition known as internal ovulation. Internal ovulations are thought to occur more frequently in high body weight hens such as broiler breeders. Yolks which are deposited into the abdominal cavity can be reabsorbed by the bird or sometimes may lead to peritonitis. However, the majority of LYF are engulfed by the infundibulum and as the follicle travels along the reproductive tract, the albumen and shell constituents are added. After the recently ovulated LYF enters the magnum, the egg's albumen is added. In the isthmus the shell membrane is added, with the ionic calcium and carbonate being deposited in the shell gland. The egg spends 18-22 h in the shell gland to deposit sufficient calcium, pigment, and cuticle over the egg. In hens approximately 5 -6 g of calcium carbonate are necessary for the formation of each eggshell (Lavelin et al., 2000). Calcium is supplied to breeders in the diet. This calcium undergoes digestion, metabolism, and eventually storage within the hen's long bones. During the dark period

calcium is drawn out of the medullary bone and transferred in the blood to the shell gland which possesses a high concentration of calcium binding protein. This protein transfers the calcium from the outside of the shell gland into the lumen where it is organized into a shell proper with its characteristic layers.

1.4.5 Egg Production and Fertility

In broiler breeder hens there generally exists a negative relationship between BW and egg production. Current breeder hens lay 140 -170 eggs/hen in a 30 wk lay cycle; however; overfeeding breeders has been shown to decrease the number of eggs produced (Kantanbaf et al., 1989; Robinson et al., 1991) and the total settable eggs (Udale et al., 1972). With high rates of egg production, the ovary is constantly functioning to recruit follicles, ovulate, and produce hatching eggs. Goerzen et al. (1996) showed that in vivo storage of sperm results in an average duration of fertility of 12.7 d following a single insemination. Spermatozoa are stored in two places within the hen's reproductive tract. The first storage site being anterior to the shell gland with the other located close to the top of the infundibulum. Spermatozoa are released and swim up the oviduct to fertilize a recently ovulated ovum.

A study by Peebles et al. (2001a) found that broiler breeder age affects embryogenesis and hatching chick BW. Renema et al. (2001) found that birds which had a greater total egg production and longer sequence lengths had more LYF at 61 wk of age and were lower in BW compared to hens with shorter sequences.

1.5 GROWTH AND SEXUAL DEVELOPMENT IN THE ROOSTER

Unlike pullets, males lack the necessary gametes at the time of hatch. The reproductive tissues of male poultry consist of two immature testes which do not have the

proper cell organization to permit sperm production. As the male grows through the rearing phase, body weight, fleshing reserves, and reproductive hormone production increases with age. Sexual development is initiated by increasing the photoperiod. This results in a dramatic increase in testicular size and a profound change in the cellular organization of these tissues which permit sperm production. Generally, cockerels will commence semen production about 2 wk after PS and usually maintain production until the time of flock dispersal. However, a proportion of males will cease sperm production and the testes will regress with the cell organization reverting back to that of an immature male.

1.5.1 Cockerel Growth

After hatching, breeder males are processed at the hatchery and then shipped to breeder complexes. Males are full-fed for 1 – 4 wk so that they get off to a good start. Genetic selection has been successful in improving growth rate and feed:gain in birds (Havenstein et al., 1994). Therefore, breeder males are feed restricted beginning at an early age to prevent excessive growth and fleshing which would limit their reproductive success in the breeder barn. Research by McGary et al. (2003) suggested that in some strains of males, skeletal conformation or excessive fleshing may prevent full cloacal contact during copulation. The period of maximal restriction of breeders occurs in the 8-12 wk period. In the rearing barn the light intensity is low and males are kept on short days with a skip a day feeding program. These management strategies have been employed in an effort to limit male mortality, reduce leg problems, and improve the uniformity/quality of breeder males.

Feed restriction of broilers and turkeys has been shown to reduce the incidence of both leg abnormalities and mortality (Hester et al., 1990; Robinson et al., 1992; and Kirn and Firman, 1993). However, Bruno et al. (2000) reported that in broilers, feed restriction negatively impacted tibia, femur, and humerus length. Research by Reddish and Lilburn (2004) found that genetic strain of broiler had a significant effect on both breast muscling characteristics and leg morphometrics (tibia and femur length). Many breeder manuals advocate that breeder males must have good feet and legs in order to maintain a high level of fertility throughout the breeding cycle (Anonymous, 1998; Anonymous, 2003).

1.5.2 Onset of Semen Production

In order for males to achieve reproductive maturity, a threshold BW, adequate fleshing, and an increased photoperiod are necessary. In the breeder barn, mortality can be an issue because breeder males were reported to display high levels of aggression toward flock mates (Millman et al., 2000). In a report by Peak and Brake (2000) the level of male mortality was 49 % for the life of a breeder flock. These authors also stated that by modifying the rearing growth profile of subsequent male flocks mortality was reduced by 8-11%. High rates of male mortality are an animal welfare issue, however the effects of high mortality have potential economic implications in the form of reduced fertility in aggressive breeder flocks.

Testicular size and cellular development are import factors which influence semen production and quality. Ultrasound equipment has been used to measure testicular size and morphology of mature breeder males (Jeanna Wilson, University of Georgia, Athens Georgia, Personal Communication, 2004). It was found that testes size was correlated to

semen production. It has been suggested that factors such as excessive muscling, skeletal conformation, and leg dimensions may negative impact male broiler breeders from effectively transferring semen to naturally mated hens (Wilson et al., 1979; Hocking and Duff, 1989; Fontana et al., 1990). As selection for growth in broilers continues to occur, the conformation of breeder males will likely evolve which could compromise reproductive ability. A great deal of research has focused on semen quality with the hope that fertility rates could be maintained by the selection of males with improved semen characteristics (mobility, concentration) (Kirby et al., 1998; Froman et al., 1999).

1.5.3 Fertility and Body Weight

Genetic selection for growth traits has been associated with reduced fertility in both turkeys (Carte and Leighton, 1969) and broiler breeders (Siegel and Dunnington, 1985). Secondary sexual characteristics and phenotypic traits have been used to characterize fertility in breeders with moderate success (McGary et al., 2002). Siegel (1965), has demonstrated that the potential for developing high mating lines of poultry exists. When high mating lines were compared to random-bred lines a difference was noted for age at sexual maturity, however no clear effect on fertility between lines was noted (Cook and Siegel, 1972). Broiler breeders are extremely efficient at utilizing excess protein to synthesize breast muscle (Hocking and Duff, 1989). Control of male BW and fleshing has resulted in an increase in the fertility of naturally mating flocks. However, there is a natural decline in fertility as a flock ages which requires additional young males being added post peak to slow the rate at which fertility declines (Spiking). Causes of poor fertility in aging flocks could relate to decreased libido in males (McGary et al., 2002), poor semen quality (Kirby et al., 1994), or inadequate insemination of hens

(McGary et al., 2003). Despite the cause of poor fertility a producer must be proactive in using management tools to quickly identify and solve the problem. Currently, post-peak lay the fertility of most broiler breeders will decline. Spiking a breeder flock has been shown to improve the ultimate fertility of a flock. After the integration of the young males, older original males resume mating thereby increasing fertility. In turn, 6 – 8 wk later the young males begin mating thereby boosting fertility a second time. In research by Wolanski et al. (2004) found BW differences between original and spiked roosters, however testes weight did not differ.

1.6 CONCLUSIONS

Hatching eggs are the unit of life for a developing chick. Although eggs are extremely durable care must be taken to provide proper storage and incubation conditions so that a high quality vigorous chick may be hatched. The residual yolk of a bird is essential for the initiation of growth and practices which maximize the use and uniformity of yolk utilization should not be underestimated. Expensive breeder chicks which are shipped from the southern United States rely heavily on yolk reserves during transportation to Canadian breeder farms.

The feed restriction of breeder parents is a necessary practice because if these birds ate free choice, their reproductive capacities would be greatly diminished. With the trend of chicken consumption increasing a steady supply of broiler meat will only be possible if producers, researchers, and breeding companies are united in an effort to maintain the reproductive capacities of broiler breeders.

1.7 DESCRIPTION OF EXPERIMENTS

Objective

The chick quality trials were designed to characterize hatch weight, residual yolk mass, and early growth rate in a broad range of genetic products from a single broiler breeder company. The on-farm trials were conducted to characterize the impact of early growth profile and chick quality of breeder males and females on bird liveability and productivity in commercial breeder flocks.

Experiments:

1. **Purpose:** To determine if genetic effects are evident for male chicks from diverse genetic backgrounds for traits such as chick quality, yolk utilization, and early growth rate.

Description: Eight genetics strains from a single primary broiler breeder company were surveyed. At hatch, 110 chicks per strain were scored for chick quality traits. Fifty of these chicks were dissected to assess residual yolk content on day 0 and the remaining birds were placed in rearing pens for a 14 d assessment of growth.

2. **Purpose:** To examine if strain differences in chick traits are related to strain differences in egg traits.

Description: Eggs (n=2100) from 10 strains of birds were obtained from a primary breeder. Fifty two eggs per strain were used to quantify yolk weight, albumen weight, and shell weight. Chicks hatched from the remaining eggs were either dissected at the day of hatch or grown for a 14 d period.

3. **Purpose:** To determine if male hatch weight and rearing growth profile influence the survivability or reproductive success of breeder males in an industry setting.

Description: Breeder males (n=550) were neck tagged and length measures were performed at hatch. Males were weighed and bone growth was characterized to 18 wk of age, which coincided with transfer to the breeder barn. At flock dispersal, males were dissected to assess reproductive condition and breast muscle fleshing. Birds that died during the 61 wk study were saved and dissected to discern the cause of mortality within the flock.

4. **Purpose:** To examine female hatch weight and rearing growth profile between two commercial flocks and relate this data to the reproductive traits at the end of each flock.

Description: Two successive flocks of breeder pullets (n=725/flock) were neck tagged at hatch and scored for chick quality traits. Birds were weighed and bone growth was characterized at hatch, 9, and 19 wk. Hens remained in the lay barn until flock dispersal at 61 wk of age; at this time tagged hens were dissected to assess ovary condition. Prior to euthanasia birds were classified as actively in-lay or out of production by visual observation of the cloaca following a standard artificial insemination protocol used on hens. This procedure should assist producers in making better culling decisions.

1.8 LITERATURE CITED

Anonymous. 1998. Arbor Acres Broiler Breeder Management Guide. Arbor Acres Farm Inc., Glastonbury, CT, USA.

Anonymous. 2003. Aviagen North America Management Guide. Aviagen North America., Huntsville, AL, USA.

Ar, A., C. V. Paganelli, R. B. Reeves, D. G. Greene, and H. Rahn. 1974. The avian egg: Water vapour conductance, shell thickness and functional pore area. The Condor 76:153-158.

Asmundson, V. S., and J. J. MacIlraith. 1948. Preincubation tests with turkey eggs. Poult. Sci. 27:394-401.

Bains, B. S. 1994. Internal egg quality influence on fertility and hatchability. World's Poult. Sci. J. 11:35-37.

Bartov, I., E, Wax, and S. Bornstein. 1994. Attempts to achieve low-weight broiler breeder hens by severe growth depression during various periods up to 6 weeks of age and food allocation below the recommendations thereafter. Br. Poult. Sci. 35:573-584.

Benton, C. E., Jr., and J. Brake. 1996. The effect of broiler breeder flock age and length of egg storage on egg albumen during early incubation. Poult. Sci. 79:1562-1565.

Brake, J., T. J. Walsh, C. E. Jr. Benton, J. N. Petitte, R. Meijerhof, and G. Peñalva. 1997. Egg handling and storage. Poult. Sci. 76:144-151.

Bruggeman, V., O, Onagbesan, E. D'Hondt, N. Buys, M. Safi, D. Vanmontfort, L. Berghman, F. Vandesande, E. Decuypere. 1999. Effects of timing of feed restriction during rearing on reproductive characteristics in broiler breeder females. Poult. Sci. 78:1424-1434.

Bruno, L. D. G., R. L. Furlan, E. B. Malheiros, and M. Macari. 2000. Influence of early quantitative food restriction on long bone growth at different environmental temperatures in broiler chickens. Br. Poult. Sci. 41:389-394.

Burke, W. H. 1992. Sex differences in incubation length and hatching weights of broiler chicks. Poult. Sci. 71:1933-1938.

Carte, I. F., and A. T. Leighton. 1969. Mating behaviour and fertility in large white turkey. Poult. Sci. 48:104-114.

Cervantes, H. 1993. A new formula for chick quality. Proc. Hatchery-Breeder Flock Management Clinic, Birmingham, AL.

Chamblee, T. N., J. D. Brake, C. D. Schultz, and J. P. Thaxton. 1992. Yolk sac absorption and intestinal growth of broilers. Poult. Sci. 71:1811-1816.

Cook, W. T., and P. B. Siegel. 1972. Evaluation of certain reproductive traits in lines of chicken selected for mating ability. Poult. Sci. 51:1201-1206.

Decuypere, E., and H. Michels. 1992. Incubation temperature as a management tool: a review. World's Poult. Sci. J. 48:28-38.

Deeming, D. C. 1989. Characteristics of unturned eggs: Critical period, retarded embryonic growth, and poor albumen utilization. Br. Poult. Sci. 30:239-249.

Ding, S. T., and M. S. Lilburn. 1996. Characterization of changes in yolk sac and liver lipids during embryonic and early post-hatch development of turkey poults. Poult. Sci. 75:478-483.

Elibol, O., and J. Brake. 2006. Effect of egg turning angle and frequency during incubation on hatchability and incidence of unhatched broiler embryos with head in the small end of the egg. Poult. Sci. 85:1433-1437.

Esteban, S., J. Rayo, M. Moreno, M. Sastre, R. Rial, and J. Tur. 1991. A role played by the vitelline diverticulum in the yolk sac resoprtion in young post-hatched chickens. J. Comp. Physiol. B. 160:645-648.

Etches, R. J. 1996. Reproduction in Poultry. CAB Int. University Press, UK.

Fasenko, G. M., F. E. Robinson, A. I. Whelan, K. M. Kremeniuk, and J. A. Walker. 2001. Prestorage incubation of long-term stored broiler breeder eggs: 1. Effects on hatchability. Poult. Sci. 80:1406-1411.

Fletcher, D. L., W. M. Britton, A. P. Rahn, and S. I. Savage. 1981. The influence of layer flock age on egg component yields and solids content. Poult. Sci. 60:983-987.

Fontana, E. A., W. D. Weaver, and H. P. Van Krey. 1990. Effects of various feeding regimens on reproduction in broiler breeder males. Poult. Sci. 69:209-216.

Freeman, B. M., and M. A. Vince. 1974. Page 163 in: Development of the Avian Embryo. Chapman and Hall, London, UK.

Froman, D. P., A. J. Feltman, M. L. Rhoads, and J. D. Kirby. 1999. Sperm mobility: A primary determinant of fertility in the domestic fowl (*Gallus domesticus*). Biol. Reprod. 61:400-405.

Funk, E. M., and H. V. Biellier. 1944. The minimum temperature for embryonic development in the domestic fowl (*Gallus domesticus*). Poult. Sci. 23:538-540.

Funk, E. M. 1950. The relationship of body weight of turkey hens to egg production, egg weight, percentage of hatch and viability of poults. Poult. Sci. 29:64-66.

Gilbert, A. B. 1971. The ovary. Pages 1163-1208 in: Physiology and Biochemistry of the Domestic Fowl. Vol. 3. D. J. Bell and B. M. Freeman, ed. Academic Press, London, UK.

Goerzen, P. R., W. L. Julsrud, and F. E. Robinson. 1996. Duration of fertility in ad libitum and feed-restricted caged broiler breeders. Poult. Sci. 75:962-965.

Hartmann, C., K. Johasnsson, E. Strandberg, and M. Wilhelmson. 2000. One-generation divergent selection on large and small yolk proportion. Br. Poult. Sci. 41:280-286.

Hartmann, C., K. Johansson, E. Strandberg, and L. Rydhmer. 2003. Genetic correlations between the maternal genetic effect on chick weight and the direct genetic effects on egg composition traits in a White Leghorn line. Poult. Sci. 82:1-8.

Hassan, E. M., and A. W. Nordskog. 1971. Effect of egg size and heterosis on embryonic growth and hatching speed. Genetics 67:279-285.

Havenstein, G. B., P. R. Ferket, S. E. Scheideler, and B. T. Larson. 1994. Growth, liveability, and feed conversion of 1957 vs. 1991 broilers when fed "typical" 1957 and 1991 broiler diets. Poult. Sci. 73:1785-1794.

Hester, P. Y., K. K. Kreuger, and M. Jackson. 1990. The effect of restrictive and compensatory growth on the incidence of leg abnormalities and performance of commercial male turkeys. Poult. Sci. 69:1731-1742.

Hocking, P. M., and S. R. I. Duff. 1989. Musculo-skeletal lesions in adult male broiler breeder fowls and their relationships with body weight and fertility at 60 weeks of age. Br. Poult. Sci. 30:777-784.

Hocking, P. M. 1993. Effects of body weight at sexual maturity and the degree and age of restriction during rearing on the ovarian follicular hierarchy of broiler breeder females. Br. Poult. Sci. 34:793-801.

Hocking, P. M., R. Bernard, R. S. Wilkie, and C. Goddard. 1994. Plasma growth-hormone and insulin growth-factor-I (Igf-I) concentration at the onset of lay in ad-libitum and restricted broiler breeder fowl. Br. Poult. Sci. 35:299-308.

Hocking, P. M., V. Zaczek, E. K. M. Jones, M. G. Macleod. 2004. Different concentrations and sources of dietary fibre may improve the welfare of female broiler breeders. Br. Poult. Sci. 45:9-19.

Hussein, S. M., R. H. Harms, and D. M. Janky. 1993. Influence of age on the yolk: albumen ratio in hen eggs. Poult. Sci. 72:594-597.

Jaap, R. G., and F. V. Muir. 1968. Erratic oviposition and egg defects in broiler-type pullets. Poult. Sci. 47:417-423.

Johnson, P. A., R. W. Dickerman, and J. M. Bahr. 1986. Decreased granulosa cell lutenizing hormone sensitivity and altered thecal estradiol concentration in the aged hen (*Gallus domesticus*). Biol. Reprod. 35:641-646.

Jones, D. R., and M. T. Musgrove. 2005. Effects of extended storage on egg quality factors. Poult. Sci. 84:1774-1777.

Kantanbaf, M. N., E. A. Dunnington, and P. B. Siegel. 1989. Restricted feeding in early and late feathering chickens. 2. Reproductive responses. Poult. Sci. 68:352-358.

Kirby, J. D., H. N. Engel, Jr., and D. P. Froman. 1994. Analysis of sub fertility associated with homozygosity of the rose comb allele in the male domestic fowl. Poult. Sci. 73:871-878.

Kirby, J. D., C. J. Tressler, and Y. K. Kirby. 1998. Evaluation of the duration of sperm fertilizing ability in five lines of commercial broiler breeder and Delaware cross males. Poult. Sci. 77:1688-1694.

Kirn, B. N., and J. D. Firman. 1993. Leg strength and performance of large white tom turkeys fed various protein and energy levels. Avian Dis. 37:37-46.

Lambson, R. O. 1970. An electron microscopic study of the entodermal cells of the yolk sac of the chick during incubation and after hatching. Am. J. Anat. 129:1-20.

Latour, M. A., E. D. Peebles, C. R. Boyle, J. D. Brake. 1994. The effects of dietary fat on growth performance, carcass composition, and feed efficiency in the broiler chick. Poult. Sci. 73:1362-1369.

Lavelin, I., N. Meiri, and M. Oines. 2000. New insight in eggshell formation. Poult. Sci. 79:1014-1017.

Leeson, S., and J. D. Summers. 1983. Consequences of increased feed allowance for growing broiler breeder pullets as a means of stimulating early maturity. Poult. Sci. 62:6-11.

Leveille, G. A., D. R. Rosmos, Y. Yeh, and E. K. O'hea. 1975. Lipid biosynthesis in the chick. A consideration of site of synthesis, influence of diet and possible regulatory mechanisms. Poult. Sci. 54:1075-1093.

MacLeod, M. G., and P. M. Hocking. 1993. Thermoregulation at high ambient temperature in genetically fat and lean broiler hens fed ad libitum or on a controlled-feeding regime. Br. Poult. Sci. 34:589-596.

Maloney, M. A., J. C. Gilbreath, J. F. Tierce, R. D. Morrison. 1967. Divergent selection for twelve-week body weight in the domestic fowl. Poult. Sci. 46:1116-1127.

Marks, H. L. 1985. Sexual dimorphism in early feed and water intake of broilers. Poult. Sci. 64:425-428.

May, J. D., and B. D. Lott. 2001. Relating weight gain and feed:gain of male and female broilers to rearing temperature. Poult. Sci. 80:581-584.

McDaniel, G. D., D. A. Roland, Sr., and M. A. Coleman. 1979. The effect of eggshell quality on hatchability and embryonic mortality. Poult. Sci. 58:10-13.

McDaniel, G. R., J. Brake, and R. D. Bushong. 1981. Factors affecting broiler breeder performance. 1. Relationship of daily feed intake level to reproductive performance of pullets. Poult. Sci. 60:307-312.

McGary, S., I. Estevez, M. R. Bakst, and D. L. Pollock. 2002. Phenotypic traits as reliable indicators of fertility in male broiler breeders. Poult. Sci. 81:102-111.

McGary, S., I. Estevez, and M. R. Bakst. 2003. Potential relationships between physical traits and male broiler breeder fertility. Poult. Sci. 82:328-337.

McGovern, R. H., R. A. Renema, F. E. Robinson. 1997. Increased feed allocation does not stimulate increased ovarian development or increase egg output in 54-week-old broiler breeder hens. Can. J. Anim. Sci. 77:177-179.

McNaughton, J. L., J. W. Deaton, F. N. Reece, and R. L. Haynes. 1978. Effects of age of parents and hatching egg weight on broiler chick mortality. Poult. Sci. 57:38-44.

Meuer, H. J., and R. Baumann. 1988. Oxygen pressure in intra- and extra embryonic blood vessels of early chick embryos. Respir. Physiol. 71:331-342.

Millman, S. T., I. J. H. Duncan, and T. M. Widowski. 2000. Male broiler breeder fowl display high levels of aggression toward females. Poult. Sci. 79:1233-1241.

Miyoshi, S., T. Mitsumoto. 1980. Selection for high and low yolk-albumen ratio in chickens, II. The direct response to selection on the yolk-albumen ratio for seven generations. Jpn. Poult. Sci. 17:219-227.

Murakami, H., Y. Akiba, and M. Horiguchi. 1988. Energy and protein utilization in newly-hatched broiler chicks-studies on early nutrition of poultry. Jpn. J. Zootech. Sci. 59:890-895.

Murakami, H., Y. Akiba, and M. Horiguchi. 1992. Growth and utilization of nutrients in newly-hatched chicks with or without removal of residual yolk. Growth Dev. Aging 56:75-84.

Noble, R. C., and J. H. Moore. 1964. Studies on the lipid metabolism of the chick embryo. Can. J. Biochem. 42:1729-1741.

Noble, R. C., F. Lonsdale, K. Connor, and D. Brown. 1986. Changes in the lipid metabolism of the chick embryo with parental age. Poult. Sci. 65:409-416.

Noy, Y., Z. Uni, and D. Sklan. 1996. Utilization of yolk in the newly hatched chick. Br. Poult. Sci. 37:987-995.

Noy, Y., and D. Sklan. 1998. Yolk utilization in the newly hatched poult. Br. Poult. Sci. 39:446-451.

Noy, Y., and D. Sklan. 1999. Energy utilization in newly hatched chicks. Poult. Sci. 78:1750-1756.

Noy, Y., and D. Sklan. 2001. Yolk and exogenous feed utilization in the post-hatch chick. Poult. Sci. 80:1490-1495.

Nitsan, Z., I. Turro-Vincent, G. Lui, E. A. Dunnington, P. B. Siegel. 1995. Intubation of weight-selected chicks with soybean oil or residual yolk: effect on early growth and development. Poult. Sci. 74:925-936.

O'Dea, E. E., G. M. Fasenko, J. J. R. Feddes, F. E. Robinson, J. C. Segura, C. A. Ouellette, and J. H. van Middelkoop. 2004. Investigating the eggshell conductance and embryonic metabolism of modern and unselected domestic avian genetic strains at two flock ages. Poult. Sci. 85:2059-2070.

O'Sullivan, N. P., E. A. Dunnington, and P. B. Siegel. 1991. Relationships among age of dam, egg component, embryo lipid transfer, and hatchability of broiler breeder eggs. Poult. Sci. 70:2180-2185.

Palmer, S.S., and J. M. Bahr. 1992. Follicle stimulating hormone increases serum oestradiol-17β concentrations, number of growing follicles and yolk deposition in aging hens (*Gallus domesticus*) with decreased egg production. Br. Poult. Sci. 33:403-414.

Peak, S. D., and J. Brake. 2000. The influence of feeding program on broiler breeder male mortality. Poult. Sci. 79 (Supp l):2. (Abstr.).

Peebles, E. D., and J. Brake. 1986. The role of the cuticle in water vapour conductance by the eggshell of broiler breeders. Poult. Sci. 65:1034-1039.

Peebles, E. D., S. M. Doyle, C. D. Zumwalt, P. D. Gerard, M. A. Latour, C. R. Boyle, and T. W. Smith. 2001a. Breeder age influences embryogenesis in broiler hatching eggs. Poult. Sci. 80:272-277.

Peebles, E. D., J. Croom, W. R. Maslin, S. K. Whitmarsh, L. R. Daniel, and I. L. Taylor. 2001b. In ovo peptide YY and epidermal growth factor administration and their effects on growth and yolk utilization in neonatal meat type chickens (*Gallus domesticus*). Comp. Biochem. Physiol. 130:741-749.

Proudfoot, F. G., H. W. Hulan, and K. B. McRae. 1982. Effect of hatching egg size from semi-dwarf and normal maternal meat parent genotype on the performance of broiler chickens. Poult. Sci. 61:655-660.

Pym, R. A. E., and J. F. Dillon. 1974. Restricted food intake and reproductive performance of broiler breeder pullets. Br. Poult. Sci. 15:245-259.

Quemeneur, P., M. Le Maniac, M. Bougie, R. L'hospitalier, P. Drouin, and M. Mallet. 1989. Vingt-troisième èpreuve pour reproducteurs de type chair 1986-1987. Bull. Inf. Stat. Exp. Avic. Ploufragan 28:1, 3-24.

Rahn, H., A. Ar, and C. V. Paganelli. 1979. How bird eggs breathe. Sci. Am. 240:46-55.

Reddish, J. M., and M. S. Lilburn. 2004. A comparison of growth and development patterns in diverse genotypes of broilers. 1. Male broiler growth. Poult. Sci. 83:1067-1071.

Renema, R. A., F. E. Robinson, and P. R. Goerzen. 2001. Effects of altering growth curve and age at photostimulation in female broiler breeders. 1. Reproductive development. Can. J. Anim. Sci. 81:467-476.

Renema, R. A., F. E. Robinson. 2004. Defining normal: comparison of feed restriction and full feeding of female broiler breeders. World's Poult. Sci. J. 60:508-522.

Ricks, C. A., N. Mendu, and P. V. Phelps. 2003. The embryonated egg: A practical target for genetic based advances to improve poultry production. Poult. Sci. 82:931-938.

Robinson F. E., W. L. Beane, C. L. Bish, P. L. Ruszler, and J. L. Baker. 1986. Modified step-up protein feeding regimens for egg-type chickens. 2. Protein level influence on growth and reproductive performance. Poult. Sci. 65:122-129.

Robinson, F. E., R. T. Hardin, and A. R. Robblee. 1990. Reproductive senescence in domestic fowl: Effects on egg production, sequence length and inter-sequence pause length. Br. Poult. Sci. 31:871-879.

Robinson, F. E., N. A. Robinson, and T. A. Scott. 1991. Reproductive performance, growth and body composition of full-fed versus restricted broiler breeder hens. Can. J. Anim. Sci. 71:549-556.

Robinson, F. E., H. L. Classen, J. A. Hanson, and D. K. Onderka. 1992. Growth performance, feed efficiency and the incidence of skeletal and metabolic diseases in full-fed and feed restricted broiler and roaster chickens. J. Appl. Poult. Res. 1:33-41.

Robinson, F. E., J. L. Wilson, M. W. Yu, G. M. Fasenko, and R. T. Hardin. 1993. The relationship between body weight and reproductive efficiency in meat type chickens. Poult. Sci. 72:912-922.

Robinson, F. E., N. A. Robinson, R. T. Hardin, and J. L. Wilson. 1995. Effects of 20-week body weight and feed allocation during early lay on growth, carcass composition, and reproductive performance of female broiler breeders. J. Appl. Poult. Res. 4:203-210.

Romanoff, A. L., and A. J. Romanoff. 1967. Page 240 in: Biochemistry of the Avian Embryo. John Wiley and Sons, New York, NY.

Siegel, P. B. 1965. Genetics of behaviour: Selection for mating ability in chickens. Genetics 52:1269-1277.

Siegel, P. B., and E. A. Dunnington. 1985. Reproductive complications associated with selection for broiler growth. Pages 55-72 in Poultry Genetics and Breeding. W. G. Hill, J. M. Manson, and D. Hewitt, ed. British Poultry Science Ltd., Longman Group, Harlow, England.

Suarez, M. E., H. R. Wilson, F. B. Mather, C. J. Wilcox, and B. N. Mcpherson. 1997. Effect of strain and age of the broiler breeder female on incubation time and chick weight. Poult. Sci. 76:1029-1036.

Sun, J., C. N. Coon. 2005. The effects of body weight, dietary fat, and feed withdrawal rate on the performance of broiler breeders. J. Appl. Poult. Res. 14:728-739.

Sun, J. M., M. P. Richards, R. W. Rosenbrough, C. M. Ashwell, J. P. McMurtry, and C. N. Coon. 2006. The relationship of body composition, feed intake, and metabolic hormones for broiler breeder females. Poult. Sci. 85:1173-1184.

Tona, K., F. Bamelis, W. Coucke, V. Bruggeman, and E. Decuypere. 2001. Relationship between broiler breeders's age and egg weight loss and embryonic mortality during incubation in large-scale conditions. J. Appl. Poult. Res. 10:221-227.

Tona, K., F. Bamelis, B. De Ketelaere, V. Bruggeman, V. M. B. Moraes, J. Buyse, O. Onagbesan, and E. Decuypere. 2003. Effects of egg storage time on spread of hatch, chick quality, and juvenile growth. Poult. Sci. 82:736-741.

Tona, K., O. Onagbesan, B. De Ketelaere, E. Decuypere, and V. Bruggeman. 2004. Effects of age of broiler breeders and egg storage on egg quality, hatchability, chick quality, chick weight, and chick post-hatch growth to forty-two days. J. Appl. Poult. Res. 13:10-18.

Tona, K., O. Onagbesan, V. Bruggeman, K. Mertens, E. Decuypere. 2005. Effects of turning duration during incubation on embryo growth, utilization of albumen, and stress regulation. Poult. Sci. 84:315-320.

Tullett, S. G. 1981. Theoretical and practical aspects of eggshell porosity. Turkeys 29:24-28.

Tullet, S. G., and F. G. Burton. 1982. Factors affecting the weight and water status of the chick at hatch. Br. Poult. Sci. 23:261-269.

Udale, R. W., P. B. Siegel, and H. P. Vankrey. 1972. Rates of ovulation and oviposition in growth selected lines of chickens. Poult. Sci. 51:2098-2100.

Uni, Z., Y, Noy, and D. Sklan. 1999. Post-hatch development of small intestine function in the poult. Poult. Sci. 78:215-222.

VanMiddlekoop, J. H. 1971. Shell abnormalities due to the presence of two eggs in the shell gland. Arch Geflügelkd. 35:122-127.

Vieira, S. L., and E. T. Jr. Moran. 1998. Eggs and chicks from broiler breeders of extremely different age. J. Appl. Poult. Res. 7:372-376.

Whitehead, C. C., 2002. Nutrition and poultry welfare. World's Poult. Sci. J. 58:349-356.

Williams, J. B., and P. J. Sharp. 1978. Ovarian morphology and rates of ovarian follicular development in laying broiler breeders and commercial egg producing hens. Br. Poult. Sci. 19:387-395.

Wilson, H. R., N. P. Piesco, E. R. Miller, and W. G. Nesbeth. 1979. Prediction of the fertility potential of broiler breeder males. World's Poult. Sci. J. 35:95-118.

Wolanski, N. J., E. J. Luiten, R. Meijerhof, A. L. J. Vereijken. 2004a. Yolk utilization and chick length as parameters for embryo development. Avian and Poult. Biol. Rev. 15:233-234.

Wolanski, N. J., R. A. Renema, F. E. Robinson, and J. L. Wilson. 2004b. End-of-season carcass and reproductive traits in original and replacement male broiler breeders. J. Appl. Poult. Res. 13:451-460.

Yalçin, S., and P. B. Siegel. 2003. Developmental stability of broiler embryos in relation to length of egg storage prior to incubation. J. Poult. Sci. 40:298-308.

Yu, M. W., F. E. Robinson, R. G. Charles, and R. Weingardt. 1992. Effects of feed allowance during rearing and breeding on female broiler breeders. 2. Ovarian morphology and production. Poult. Sci. 71:1750-1761.

Zuidhof, M. J., F. E. Robinson, J. J. R. Feddes, R. T. Hardin, J. L. Wilson, R. I. McKay, M. Newcombe. 1995. The effects of nutrient dilution on the well-being and performance of female broiler breeders. Poult. Sci. 74:441-456.

2.0 RELATIONSHIPS AMONG EGG CHARACTERISTICS, CHICK MEASUREMENTS, AND EARLY GROWTH TRAITS IN TEN BROILER BREEDER STRAINS[1]

2.1 INTRODUCTION

Hen age, egg storage conditions, and genetic strain influence the hatchability, chick quality, and broiler growth (Lapão et al., 1999; Yang et al., 1999; Tona et al., 2003). Wolanski et al. (2006) suggested that some broiler strains utilize yolk reserves more efficiently than others when incubated with a common incubational profile. A study by Tona et al. (2004) compared the metabolic heat production in three lines of broiler breeders varying in growth rate and found that selection criteria was linked to embryonic metabolism. This research demonstrated that embryonic heat production of the high yielding standard line was significantly greater than that of the labile line (least selection on growth) with the experimental line (moderate selection on growth) being intermediate. Siegel et al. (1968) and Suarez et al. (1997) observed differences in incubation time for various genotypes and these authors suggested that incubation profiles may need to be adjusted to optimize hatchability and performance especially in higher yielding strains.

Chick quality is difficult to evaluate at hatch. Traditionally hatch weight has been emphasized as a strong indicator of chick quality however; recent research (Joseph et al., 2006) has shown that hatch weight differences between treatments were largely explained by variations in residual yolk mass. Residual yolk in newly hatched chicks can account for as much as 20 % or 8 g of hatch weight (Noy et al., 1996) whereas

[1] A version of this chapter has been accepted for publication Wolanski et al 2007. Poultry Science 86:

Vieira and Moran, (1998) reported yolk to constitute roughly 10 % (4.5 to 5.0 g) of a chick's BW. Residual yolk mass can be extremely variable among genetic strains at hatch – ranging from 0.8 to 10.6 g (Wolanski et al., 2006). Furthermore, length measurements of chicks at hatch have been found to correlate more strongly with 14 d BW than initial hatch weight and 14 d BW. In an effort to better quantify chick quality, an abdomen scoring system has been implemented to estimate residual yolk mass of live chicks. This score correlated with actual residual yolk mass after dissection ($r = 0.50$; $P < 0.0001$) (Wolanski et al., 2006).

The objectives of this study were to evaluate egg characteristics, internal chick components, and relative growth rate of ten strains of broiler breeders. It was believed that residual yolk mass at hatch would play a role in determining hatch weight. The genetic diversity evaluated in this trial would result in observable differences in egg characteristics that would be linked to hatch traits in the chicks. It was anticipated that hatch traits would be related to the chick traits at 14 d of age.

2.2 MATERIALS AND METHODS

A total of 2100 eggs from ten broiler breeder genotypes (Table 2-1) were obtained from a primary breeding company (Aviagen North America, Huntsville, AL). Flock age ranged between 46 wk (Strain 10) and 57 wk (Strain 9) for the strains investigated in this trial. All eggs were collected in a 24 h period. The eggs were weighed on the day of lay at a central egg depot in the Southern United States and shipped to the University of Alberta. Upon arrival, (8 d after collection) eggs were reweighed and randomly allocated to one of three fates: 1) egg quality eggs (52

eggs/strain), 2) eggs for conductance (8 eggs/strain), 3) incubation eggs (150 eggs/strain).

2.2.1 Eggs for Egg Quality

Eggs used for determination of egg quality were stored for 1 d in the hatchery cooler at 15 C and 70 % RH. The following morning eggs were taken from the cooler and allowed to warm to room temperature and reweighed before specific gravity was measured. The flotation method (Hamilton, 1982) was used to determine specific gravity with a range of salt solutions from 1.064 - 1.110 with increments of 0.002. Eggs were then rinsed in cool water and broken open to determine yolk and albumen characteristics of the eggs. The height of the albumen was measured using a digital albumen height gauge (TSS, York, England). The measurement was taken in the thick albumen surrounding the egg yolk. Yolk was then weighed and the mass of albumen was calculated as the difference of egg weight after the yolk and shell weight were obtained. Shells were rinsed in warm tap water and air dried at room temperature for 4 d after which, determination of egg shell weight and shell thickness were performed. Shell thickness was measured with a digital micrometer (TSS, York, England).

2.2.2 Eggs for Conductance

Eggs destined for conductance were sealed in desiccators filled with Drierite dessicant (W. A Hammond Drierite Company Ltd., Xenia, OH). Eggs from each strain were represented in each of the eight desiccation chambers. Eggs were weighed at 24 hr intervals for a total of 13 days to characterize moisture loss and calculate eggshell conductance.

2.2.3 Eggs for Incubation

The remaining eggs were placed in a 5,000-egg-capacity incubator (Jamesway Incubator Company Inc., Cambridge, Ontario, Canada). The flats were randomly placed in the incubator to minimize potential airflow or incubator effects. At 18 d of incubation, eggs were candled and infertile eggs and early dead embryos were removed. Macroscopic inspection of eggs removed at candling was performed to determine fertility status or the stage of embryonic death. Eggs were transferred into individual pedigree hatch baskets so that chick traits could be traced back to initial egg weight. The hatch was pulled at 21.5 d and chicks were processed. All unhatched eggs were broken open to macroscopically determine fertility or stage of development at death. At hatch, all chicks were neck tagged (Heartland Animal Health Inc., Fair Play, MO), weighed, and subjected to chick quality measures. Of particular interest was the consistency and fullness of the chick's abdomen. Chick length and shank length were also characterized for each chick (Wolanski et al., 2006). Navel condition was also determined (data not presented).

At hatch, 50 chicks/strain were randomly selected for characterization and euthanized by cervical dislocation. Chick weight, residual yolk mass, internal organ weights, and breast muscle fleshing was quantified after birds had been euthanized. The remaining birds were measured and placed in rearing pens for a period of 2 wk. Birds had ad libitum access to broiler starter diet (Table 2-2) and water, with a photoperiod of 23 L and 1 D. At 14 d all birds were processed to measure breast muscle weight, residual yolk weight, and carcass morphometrics such as keel length, shank length, and total bird length.

2.2.4 Statistical Analysis

Data were analyzed as a one-way ANOVA using the GLM procedures of SAS and means were separated using the PDIFF *t*-test procedure (SAS System, 2002). Pearson correlation coefficients were calculated between means of interest. The bird was the experimental unit for measurements taken at hatch. The pen was the experimental unit for growth traits as well as conformation and carcass traits recorded at 14 d of age. Significance was assessed at a $P < 0.05$.

2.3 RESULTS AND DISCUSSION

2.3.1 Egg Quality Characteristics

Egg, yolk, albumen and shell weights are summarized in Table 2-3, along with the egg quality measures of egg specific gravity, shell thickness and albumen height. The range in egg weight was 3.0 g for the 10 strains investigated in this trial. The largest hatching eggs (66.0 g) were produced by Strain 2 – a female line bird that has been selected for reproductive traits. In contrast, Strains 4, 9, and 10 had mean egg weights of 63.0, 63.4, and 63.6 g respectively. Interestingly, the flock ages of Strains 4, 9, and 10 were 50, 57, and 46 wk of age respectively. These data suggest that strain effects in this study had a more profound impact on egg weight rather than breeder flock age.

Yolk weight varied with genetic strain from a high of 22.6 g for Strain 8 to a low of 20.9 g for Strains 7 and 10 (Table 2-3). Ultimately, the range in average yolk weight (1.5 g) accounted for approximately 50 % of the variation observed in egg weight. The range in shell weight was about 0.5 g with the remaining difference in egg weight being explained by variations in albumen weight. Albumen is the primary source of water in the egg and Finkler et al. (1998) suggested that albumen weight in hatching eggs was the

primary determinant of hatchling size. The female line (Strain 2) had the greatest amount of albumen on both and absolute (38.8 g) and proportionally (59.0 %) and chicks from this strain hatched with the greatest BW. The youngest flock, Strain 10 (46 wk), had the highest albumen height 5.22 mm as compared to older flocks, Strains 9, 5, 3 (57, 54, 52 wk), which had albumen heights of 4.36, 4.38, and 4.20 mm in height, respectively. The female line birds selected for yield (Strain 2) had an albumen height of 5.23 mm. Both age and strain may impact the internal contents (yolk and albumen) weight and composition of the hatching eggs, which may influence the hatching characteristics of each strain. Peebles et al. (2000) suggested that albumen height may be a factor in determining dry matter accumulation of chicken embryos and these authors also reported that thick albumen may slow gas diffusion, limit nutrient availability, and decreased embryonic growth. Albumen height was 5.00 mm after 12 h of incubation and by 60 h the albumen was 3.59 mm (Lapão et al 1999).

The eggs of Strain 1, which was a male line, had the highest shell weight and shell thickness (Table 2-3). This strain had a mean egg weight of 64.8 g. This heavily growth-selected strain had poorer egg production than all other strains (F. E. Robinson, unpublished data), which may allow more calcium to be deposit onto an eggshell. The selection criteria used to develop the male line (Strain 1) placed the majority of selection pressure on growth and BW while selection on egg production was compromised. Frame size of male line females was larger (F. E. Robinson, unpublished data), potentially allowing for more storage of medullary bone utilized in the formation of egg shell constituents. Riczu et al. (2004) reported that BW was correlated with total bone density in laying hens. A report by Silversides et al. (2006) described strain effects on shell

quality of layer chickens with the largest strain producing the heaviest egg shell and the lightest strain producing a smaller egg with a lighter eggshell weight.

2.3.2 Eggshell Conductance

The initial egg weight, moisture loss, and % moisture loss data are reported in Table 2-4. The oldest strain (Strain 9) had the greatest moisture loss to 4 d (3.01 g) as compared to the female line (Strain 3), which lost only 2.21 g in the same period of time. On a percentage basis Strain 1 eggs lost 4.60 % of its weight compared to only 3.46 % in the female line eggs. This result was likely associated with age but some of the selection for reproductive traits in (Strain 3) may have had a positive impact on moisture retention in this line as the two breeder flocks were only 5 wk apart in age. It has been reported that water loss from eggs was inversely proportional to shell thickness (Tullett and Board, 1977). The number and size of pores in each egg can influence the rate of moisture loss and heat conductance across the eggshell (Hulet et al., 2007). Strain 4 had the thickest shells being 0.368 mm, which may explain why for the egg desiccation data this strain lost only 3.55 % and 2.71 % of moisture from d 0 to 4 and d 4 to 11 (Table 2-4).

2.3.3 Egg Weight and Characteristics of Incubated Eggs

Female line Strains 2 and 3 had fresh egg weights of 66.9 and 65.4 g respectively (Table 2-5). Although Strain 10 was a female line, the breeder flock age that these eggs were obtained from was 6 and 7 wk younger than Strain 2 or 3 breeders, respectively. This suggests that the almost 3.3 g and 1.8 g difference in egg weight in relation to the other female lines (Strains 2 and 3) may be partially explained by differences in flock age. However, it should be noted that Strain 9, which was the oldest flock (57 wk), had hatching eggs that were among the lightest (63.8 g) of all strains examined,

demonstrating that age along with other factors may contribute equally to differences in egg weight. Joseph et al. (2002) compared 3 breeder strains and reported that the strain with the best rate of lay produced significantly lighter eggs.

During transport eggs invariably lose mass due to evaporation. In this trial Strains 9 and 5 lost the highest percentage of their initial weight (1.31% and 1.23% respectively) during transport. The moisture loss percentage calculated at transfer for the hatching eggs ranged from 12.1 % in Strain 3 (female line with emphasis of selection based on reproductive traits) to a high of 13.7 % in Strain 7 (fast feathering commercial cross selected for total carcass yield). This weight loss was not ultimately related to shell conductance (Table 2-6), which demonstrated a different ranking among strains.

2.3.4 Hatch Weight Relative to Egg Weight

Egg weight is a dominant factor in determining chick hatch weight (Wyatt et al., 1985). In this study the large male line hens (Strain 1) produced eggs which were among the largest hatching eggs being 65.8 g and had the greatest hatch weight 46.3 g (Table 2-6). Egg weights for female lines (Strains 2 and 3) were significantly different (being 66.9 and 65.4 g respectively) whereas both hatch weights (46.6 and 45.4 g, respectively) and carcass weight of dissected chicks (36.2 and 35.4 g respectively) did not differ. Also, Strain 10 (a female line with emphasis on reproduction) produced eggs which were nearly 2 g smaller than Strain 3 however the chick weight and carcass weights were comparable to Strain 3. Pal et al. (2002) has shown that the wet as well as dry weight of pre-hatched chicks was significantly altered by genotype as well as stage of incubation in broiler and layer chicks. Furthermore, Hardin (1972) stated that weight of pre-hatched chicks of different breeds is not merely associated with differences in egg weight, but

reflected true genetic differences. Christensen et al. (2002) reported that line, age, and storage factors along with the interaction of these factors affect embryonic body and organ weights differently. Although numerous factors influence chick weight at hatch Ricklefs and Starck (1998) stated that egg weight and the length of the incubation period have an impact on hatch weight.

2.3.5 Residual Yolk and Albumen

Recent research, (Finkler et al., 1998) has suggested that albumen volume is an important determinant of hatchling size. When expressing chick yields in terms of egg weight there is a great deal of variation in the conversion of egg contents into chick body mass. Strain 1 (male line) chicks weighed 70.4 % of the initial egg weight yet Strains 5, 6, 7 (commercial Strains) had the lowest chick yields being 67.2, 67.5, and 66.9 %. Although the yields of the commercial strains (5, 6, and 7) are low when compared to the male line chicks; after considering the dissection results at hatch, residual yolk content for the commercial strains were the lowest of all strains investigated. This evidence suggests that these commercial strains had already converted yolk reserves into body tissues and therefore had less residual yolk, which is a component of hatch weight. Strain 4 (commercial product whole bird market) had the next least amount of residual yolk being 4.4 g. Incubating eggs under commercial conditions may inadvertently be optimizing incubation conditions for the commercial strains. These birds tend to have more in common with regard to rate of lay, egg sizes, and relative yolk weight than they do with the more specialized lines. Although the male line Strain 1 had the largest hatch weight and chick yield it also possessed the greatest amount of residual yolk (5.5 g). Siegel et al. (2006) found that male line poults had larger residual yolk sacs both on an

absolute basis and as a percentage of live weight when compared to female line poults. This suggests that incubation conditions may have been suboptimal for efficient yolk utilization in the heavily growth selected male line. Research by Tona et al. (2004) has suggested that current higher yielding strains possess a higher metabolic rate throughout incubation. Consequently; the airflow in the hatchers must be adequate to dissipate the excess heat and CO_2 produced due to increased metabolic activity. Sklan et al. (2003) clearly showed that residual yolk sac weight of chicks at hatch increases linearly as maternal flock age increases.

Yolk utilization on a percentage of chick weight basis showed that the male line (Strain 1) had 13.5 % of total hatch weight in the form of unutilized residual yolk as compared to the commercial Strains 5, 6, 7 which had only 9.4, 9.2, and 9.7 % of initial hatch weight in the form of residual yolk (Table 2-6). The early mobilization of yolk lipids in these strains may explain why they had the greatest proportion of liver at the time of hatch (2.84, 2.80 2.83 % respectively). Strains that had a significantly greater amount of residual yolk (Strains 1 and 2) had significantly lower weights of liver on a percentage basis being 2.56 and 2.37 %, respectively. In a report by Sklan et al. (2003) hepatic size was relatively larger in chicks that exhibited greater growth, which the authors suggested may reflect the level of metabolic activity. It is well recognized that the liver is necessary for the remodeling of residual yolk lipids into lipoprotein particles that are exported into circulation (Sklan et al., 2003).

2.3.6 14 d Growth Data

Hatch weight is reported in Table 2-6 while, growth data, external morphometrics and dissection results are reported in Table 2-7. Male line chicks (Strain 1) had the

longest shank, keel, and total length measurements at 14 d of age (Table 2-7). Strain 1 was among the heaviest chicks at hatch and by 7 d of age this strain was 15 % heavier than the slow feathering commercial cross (Strain 8). The 15 % relative difference between Strains 1 and 8 generally remained constant throughout the grow-out period. The male line strain (Strain 1) had the highest relative BW gain from hatch to 14 d (765 %). Commercial strains (Strains 4, 5, and 6) had relative BW gains of 615, 546, and 518 % respectively. Strain 6 had the greatest degree of selection on white meat yield and the slowest relative growth rate of all strains investigated. Wilson (1991) reported that every 1 g increase in hatch weight resulted in an 8 to 13 g advantage in broiler market weight in the 1980's. This emphasizes the importance of suiting incubation conditions to allow for optimal broiler growth during incubation. Scheuermann et al. (2003) compared chick growth and muscle development in 8 strain crosses and suggested that different growth curves exist among commercially available strain crosses.

2.3.7 14 d Dissection Data

The dissection results for the chicks at 14 d in terms of breast muscle, liver, and heart weights are provided in Table 2-7. Breast meat weight for the 10 strains ranged from 51 g in the heavily growth selected male line (Strain 1) to a low of 30 g in the Strain 3 birds which were predominately selected based on female reproductive performance. Remignon et al. (1994; 1995) reported that fast-growing lines of chickens have 15-20 % more myofibers than slower growing lines. Therefore, some of the difference in breast muscle yield in this trial may relate to an increased number of myofibers in the heavily growth selected Strain 1 chicks relative to other strains.

In the industry the balance between BW and reproduction has been well documented, and it appears that selection criteria used to develop the divergent genotypes in this study has had an impact on traits of extremely young birds. On a percentage basis, the breast muscle weight of Strain 1 accounts for 13 % of BW as compared to 10 % in Strain 3 at 14 d. With the commercial products, Strains 4, 5, 6, there is an increasing gradient in the degree of selection for white meat yield, with Strain 4 having the least emphasis and Strain 6 having the greatest. This is demonstrated by the white meat yield performance of Strain 4 with 10.9% breast muscle compared to Strains 5 and 6 with 11.6% and 11.8 %, respectively. The liver, which is a supply organ, showed a great deal of variation based on body size with the largest male line strain (Strain 1) having a mean liver weight of 15.5 g as compared to the commercial birds (Strains 4, 5, 6) which had mean liver weights of 11.3, 10.4, and 10.1 g respectively. However, when liver was expressed on a percentage basis female line Strains 10 and 2 had an advantage when compared to the commercial Strains (5, 6, and 7) (Table 2-7). Heart weight ranged from 2.2 g in Strains 6 and 10 to a high of 3.3 g in Strain 1. Cardio-vascular fitness in commercial broilers may help to prevent mortality associated with ascites or other metabolic diseases. When examining the relative heart weight in the 10 strains surveyed the commercial lines (Strains 5, 6, and 7) had the greatest percent heart (0.84, 0.83, and 0.81 % respectively). The internal organ weights were correlated with BW and consistently showed that the male line (Strain 1) had the largest absolute internal organ weights by 14 d.

2.3.8 Correlations and CV's

Correlations among egg characteristics and fresh egg weight are reported in Table 2-8. Both albumen weight and yolk weight were significantly correlated with fresh egg weight. However albumen weight had a correlation coefficient of ($r = 0.84$) while yolk had a ($r = 0.48$). In this trial shell weight was strongly correlated with shell thickness ($r = 0.78$). This finding was in partial agreement with a report by Zhang et al. (2005) who described a moderate but significant correlation between egg shell weight and egg shell thickness.

The correlations of various hatch traits to fresh egg weight reveals that egg weight significantly correlated with most traits investigated in this trial (Table 2-9). The correlation between fresh egg weight and hatch weight was $r = 0.87$, corroborating previous reports demonstrating 86 to 97 % of the variation in chick weight to be explained by set egg weight (Tullett and Burton, 1982; and Burke, 1992). Hatch weight was found to correlate with both wet residual yolk weight ($r = 0.67$) and wet carcass weight ($r = 0.83$) in chicks dissected at hatch. In agreement with a previous study by Wolanski et al. (2006) the live abdomen score was significantly correlated with dissected residual yolk mass ($r = 0.50$).

The coefficient of variance (CV) in fresh egg weight was low for all strains investigated, ranging from a high of 8.1 % in Strain 7 to a low of 5.9 % in Strain 8 (Table 2-10). The range in CV of chick weight at hatch was comparable to that of the CV for egg weight being 7.1 % in Strain 8 and 9.5 % in Strain 7 (Table 2-10). It is interesting to note that the variation increased in Strain 7 while chick weight was less variable than for the eggs set for Strain 8. The greatest CV for all traits examined in this trial was found

for wet residual yolk content of hatched chicks. This variable had a CV ranging from 25.9 % in Strain 2 (female line selected bird) to a high of 42.5 % in Strain 7. This high degree of variation suggests that some chicks were efficiently utilizing yolk reserves prior to hatch while others had not utilized residual yolk reserves to the same extent. From the CV data, yolk utilization was five times more variable than the variation observed in initial egg weight data and chick weight data.

These data provide support that more emphasis should be placed on optimizing incubation conditions that allow for more uniform yolk utilization at the time of hatch thus resulting in improved chick quality. Characterizing egg traits, chick morphology, residual yolk sac mass and growth traits across a range of strains can provide valuable data to assist in this process. While eggs in this trial were incubated according to industry practices, further research is needed to evaluate specific incubation conditions for the broiler industry that continues to develop new strains.

2.4 REFERENCES

Burke, W. H. 1992. Sex differences in incubation length and hatching weights of broiler chicks. Poult. Sci. 71:1933-1938.

Christensen, V. L., M. J. Wineland, G. M. Fasenko, and W. E. Donaldson. 2002. Egg storage alters weight of supply and demand organs of broiler chicken embryos. Poult. Sci. 81:1738-1743.

Finkler, M. S., J. B. van Orman, and P. R. Southerland. 1998. Experimental manipulation of egg quality in chickens: influence of albumen and yolk on the size and body composition of near-term embryos in a precocial bird. J. Comp. Physiol. 168:17-24.

Hamilton, R. M. G. 1982. Methods and factors that affect the measurement of shell quality. Poult. Sci. 61:2022-2039.

Hardin, R. T. 1972. Growth of bantam breeds of poultry. 1. Embryonic. Poult. Sci. 51:283-286.

Hulet, R., G. Gladys, D. Hill, R. Meijerhof, and T. El-Shiekh. 2007. Influence of egg shell embryonic incubation temperature and broiler breeder flock age on posthatch growth performance and carcass characteristics. Poult. Sci. 86:408-412.

Joseph, N. S., A. A. J. Dulaney, F. E. Robinson, R. A. Renema, and M. J. Zuidhof. 2002. The effects of age at photostimulation and dietary protein intake on reproductive efficiency in three strains of broiler breeders varying in breast yield. Poult. Sci. 81:597-607.

Joseph, N. S., A. Lourens, E. T. Jr. Moran. 2006. The effects of suboptimal eggshell temperature during incubation on broiler chick quality, live performance, and further processing yield. Poult. Sci. 85:932-938.

Lapão, C., L. T. Gama, M. C. Soares. 1999. Effects of broiler breeder age and length of egg storage on albumen characteristics and hatchability. Poult. Sci. 78:640-645.

Noy, Y., Z. Uni, and D. Sklan. 1996. Routes of yolk utilization in the newly-hatched chick. Br. Poult. Sci. 37:987-996.

Pal, A. K., M. A. Quadri, S. B. Jadhao, J. Kumbhakar, H. S. Kushwah, and I. C. Datta. 2002. Genotype influences body composition of developing chicken embryo. Pak. J. Nutr. 1:82-84.

Peebles, E. D., C. W. Gardner, J. Brake, C. E. Benton, J. J. Bruzual, and P. D. Gerard. 2000. Albumen height and yolk and embryo compositions in broiler hatching eggs during incubation. Poult. Sci. 79:1373-1377.

Remignon, H., L. Lefaucheur, J. C. Blum, and F. H. Ricard. 1994. Effects of divergent selection for body weight on three skeletal muscles characteristics in the chicken. Br. Poult. Sci. 35:65-76.

Remignon, H., M. F. Gardahaut, G. Marche, and F. H. Ricard. 1995. Selection for rapid growth increases the number and the size of muscle fibers without changing their typing in chickens. J. Muscle Res. Cell. Motil. 16:95-102.

Ricklefs, R. E., and M. J. Starck. 1998. Embryonic growth and development. Pages 31-58 in: Avian Growth and Development. Oxford University Press, New York, NY.

Riczu, C. M., J. L. Saunders-Blades, Á. K. Yngvesson, F. E. Robinson, and D. R. Korver. 2004. End-of-cycle bone quality in white- and brown-egg laying hens. Poult. Sci. 83:375-383.

SAS System (2002) SAS 9.1. Copyright (c) 2002-2003 by SAS Institute Inc., Cary, NC, USA.

Scheuermann, G. N., S. F. Bilgili, J. B. Hess, D. R. Mulvaney. 2003. Breast muscle development in commercial broiler chickens. Poult. Sci. 82:1648-1658.

Siegel, P. B., J. W. Coleman, H. B. Graves, and R. E. Phillips. 1968. Incubation period of chicken selected bidirectionally for juvenile body weight. Poult. Sci. 47:105-107.

Siegel, P. B., M. Blair, W. B. Gross, B. Meldrum, C. Larsen, K. Boa-Amponsem, D. A. Emmerson. 2006. Poult performance as influenced by age of dam, genetic line, and dietary vitamin E. Poult. Sci. 85:939-942.

Silversides, F. G., D. R. Korver, and K. L. Budgell. 2006. Effects of strain of layer and age at photostimulation on egg production, egg quality, and bone strength. Poult. Sci. 85:1136-1144.

Sklan, D., S. Heifetz, and O. Halevy. 2003. Heavier chicks at hatch improves marketing body weight by enhancing skeletal muscle growth. Poult. Sci. 82:1778-1786.

Suarez, M. E., H. R. Wilson, F. B. Mather, C. J. Wilcox, and B. N. Mcpherson. 1997. Effect of strain and age of the broiler breeder female on incubation time and chick weight. Poult. Sci. 76:1029-1036.

Tona, K., R. D. Malheiros, F. R. Bamelis, C. Careghi, V. M. B. Moraes, O. Onagbesan, E. Decuypere, and V. Bruggeman. 2003. Effects of storage time on incubating eggs gas pressure, thyroid hormones, and corticosterone levels in embryos and on their hatching parameters. Poult. Sci. 82:840-845.

Tona, K., O. M. Onagbesan, Y. Jego, B. Kamers, E. Decuypere, and V. Bruggeman. 2004. Comparison of embryo physiological parameters during incubation, chick quality, and growth performance of three lines of broiler breeders differing in genetic composition and growth rate. Poult. Sci. 83:507-513.

Tullett, S. G., and R. G. Board. 1977. Determinants of avian eggshell porosity. J. Zool. (London) 183:203-211.

Tullet, S. G., and F. G. Burton. 1982. Factors affecting the weight and water status of the chick at hatch. Br. Poult. Sci. 23:261-269.

Vieira, S. L., and E. T. Jr. Moran. 1998. Broiler chicks hatched from egg weight extremes and diverse breeder strains. J. Appl. Poult. Res. 7:392-402.

Wilson, H. R. 1991. Interrelationships of egg size, chick size, post-hatching growth and hatchability. World's Poult. Sci. J. 47:5-16.

Wolanski, N. J., R. A. Renema, F.E. Robinson, V. L. Carney, and B. I. Fancher. 2006. Relationship between chick conformation and quality measures with early growth traits in males of eight selected pure or commercial broiler breeder strains. Poult. Sci. 85:1490-1497.

Wyatt, C. L., W. D. Weaver, Jr., and W. L. Beane. 1985. Influence of egg size, eggshell quality and posthatch holding time on broiler performance. Poult. Sci. 64:2049-2055.

Yang, A., D. A. Emmerson, E. A. Dunnington, and P. B. Siegel. 1999. Heterosis and developmental stability of body and organ weights at hatch for parental line broiler breeders and specific crosses among them. Poult. Sci. 78:942-948.

Zhang, L. C., Z. H. Ning, G. Y. Xu, Z. C. Hou, and N. Yang. 2005. Heritabilities and genetic and phenotypic correlations of egg quality traits in brown-egg dwarf layers. Poult. Sci. 84:1209-1213.

TABLE 2-1. Description and the main selection criteria of ten broiler breeder strains

Strain	Selection criteria	Breeder Flock Age (wk)
1	Growth rate, feed conversion rate, and carcass yield	50
2	Female line selection for yield	53
3	Female line emphasis reproduction	52
4	Commercial product designed for the whole bird market	50
5	Commercial product designed for the deboned market	54
6	Commercial product designed for increased white meat yield	51
7	Commercial fast feathering multipurpose product	50
8	Commercial slow feathering multipurpose product	50
9	Faster growth, designed for fast food market	57
10	Female line emphasis reproduction	46

TABLE 2-2. Composition of broiler starter diet fed from day 0 to end of trial (14 d)

Ingredients	Proportion (%)
Corn	18.00
Vegetable fat	3.77
Canola oil	4.93
Fish meal	3.00
Soybean meal	26.87
Wheat	42.93
Dicalcium phosphate	1.55
Calcium carbonate	1.50
Broiler premix[1]	0.50
Choline chloride premix[2]	0.50
Salt	0.42
L-lysine	0.23
DL-methionine	0.28
L-threonine	0.05
Vitamin E 5000 IU/KG	0.30
Calculated composition	
ME (kcal/kg)	3,067
Crude Protein	23.0

[1] Broiler premix provided per kilogram of diet: vitamin A (retinyl acetate), 10,000 IU; cholecalciferol, 2,500 IU; vitamin E (DL-α-tocopheryl acetate), 35 IU; vitamin K, 2 mg; pantothenic acid, 14 mg; riboflavin, 5.0 mg; folacin, 0.8 mg; niacin, 65 mg; thiamine, 2.0 mg; pyridoxine, 4.0 mg; vitamin B12, 0.015 mg; biotin, 0.18 mg; iodine, 0.5 mg; Mn, 70mg; Cu, 8.5 mg; Zn, 80 mg; Se, 0.1 mg; Fe, 100 mg.

[2] Provided choline chloride in the diet at a level of 100 mg/kg.

TABLE 2-3. Comparison of egg traits and egg components for ten strains of broiler breeders[1]

Strain	Egg weight (g)	Yolk weight (g)	Yolk weight %[2]	Albumen weight (g)	Albumen weight %[2]	Albumen height (mm)	Shell weight (g)	Shell weight %[2]	Shell thickness (mm)[3]	Specific gravity[4]
1	64.8^{abcd}	21.9^{bcd}	33.8^{b}	37.2^{bcd}	57.4^{cd}	4.58^{cd}	5.76^{a}	8.9^{a}	0.370^{a}	1.0717^{a}
2	66.0^{a}	21.4^{cde}	32.6^{c}	38.8^{a}	59.0^{a}	5.23^{a}	5.48^{bc}	8.3^{c}	0.333^{de}	1.0683^{e}
3	65.8^{ab}	22.0^{abc}	33.4^{bc}	38.4^{ab}	58.3^{abc}	4.20^{e}	5.46^{bcd}	8.3^{c}	0.340^{bcd}	1.0684^{e}
4	63.0^{e}	21.2^{de}	33.8^{b}	36.2^{de}	57.5^{bcd}	4.19^{e}	5.56^{ab}	8.8^{a}	0.368^{a}	1.0704^{abcd}
5	65.3^{abc}	22.0^{abc}	33.7^{b}	37.5^{bc}	57.5^{bcd}	4.38^{de}	5.76^{a}	8.8^{a}	0.351^{b}	1.0715^{ab}
6	64.3^{bcde}	21.5^{cde}	33.3^{bc}	37.5^{bc}	58.2^{abc}	5.23^{a}	5.47^{bcd}	8.5^{bc}	0.338^{cd}	1.0699^{bcde}
7	63.6^{de}	20.9^{e}	32.9^{bc}	37.5^{bcd}	58.9^{a}	5.06^{ab}	5.25^{d}	8.3^{c}	0.325^{e}	1.0689^{cde}
8	64.2^{cde}	22.6^{a}	35.2^{a}	36.4^{cde}	56.5^{de}	4.77^{bc}	5.36^{bcd}	8.4^{c}	0.333^{de}	1.0689^{de}
9	63.4^{de}	22.6^{ab}	35.5^{a}	35.7^{e}	56.1^{e}	4.36^{de}	5.29^{cd}	8.3^{c}	0.328^{de}	1.0684^{e}
10	63.6^{de}	20.9^{e}	32.9^{bc}	37.2^{bcd}	58.5^{ab}	5.22^{a}	5.53^{b}	8.7^{ab}	0.350^{bc}	1.0707^{abc}
SEM	0.6	0.3	0.4	0.5	0.4	0.14	0.08	0.1	0.005	0.0068

[a-e]Means within a column with different superscripts differ significantly ($p \leq 0.05$).

[1]For all variables measured n = 52 eggs/strain.

[2]Component weight expressed as a percentage of egg weight.

[3]Shell thickness was measured in the middle of the egg shell using a digital micrometer.

[4]Measured using saline solutions with specific gravities ranging from 1.064-1.110 with increments of 0.002.

Table 2-4. Comparison of egg desiccation results for ten strains of broiler breeders[1]

Strain	Fresh egg weight (g)	Moisture loss to 4 d (g)	Moisture loss to 4 d (%)[2]	Moisture loss 4-11 d (g)	Moisture loss 4-11 d (%)[2]	Relative eggshell conductance (mgH20/d/Torr/100g)
1	65.7^{a}	2.60^{b}	3.92^{bc}	2.24^{a}	3.36^{ab}	19.9^{a}
2	65.7^{a}	2.52^{bc}	3.80^{bc}	2.15^{ab}	3.23^{abc}	19.3^{ab}
3	63.6^{ab}	2.21^{c}	3.46^{c}	1.79^{bcd}	2.80^{bcd}	16.6^{abc}
4	63.3^{ab}	2.28^{bc}	3.55^{c}	1.74^{cd}	2.71^{cd}	15.7^{bc}
5	63.0^{ab}	2.34^{bc}	3.66^{c}	1.56^{d}	2.42^{d}	14.2^{c}
6	60.3^{b}	2.61^{b}	4.29^{ab}	2.25^{a}	3.70^{a}	18.2^{ab}
7	62.4^{ab}	2.31^{bc}	3.66^{c}	1.98^{abc}	3.13^{abc}	16.6^{abc}
8	63.0^{ab}	2.48^{bc}	3.90^{bc}	1.98^{abc}	3.09^{bc}	16.6^{abc}
9	64.6^{a}	3.01^{a}	4.60^{a}	2.16^{ab}	3.28^{abc}	18.6^{ab}
10	64.0^{ab}	2.35^{bc}	3.64^{c}	1.96^{abc}	3.04^{bc}	17.7^{abc}
SEM	1.5	0.13	0.21	0.15	0.22	1.37

$^{a-d}$Means within a column with different superscripts differ significantly ($p \leq 0.05$).

[1]For all variables measured n = 8 eggs/strain.

[2]All percentage data expressed as a percentage of fresh egg weight.

Table 2-5. Chick weight and hatching egg measurements of ten broiler breeder strains[1]

	Egg weight			Egg weight loss			
	Fresh	Set	Transfer	% set	% transfer	Chick weight	
Strain	(g)	(g)	(g)	loss[2]	loss[2]	(g)	%[2]
1	65.8^{ab}	65.4^{ab}	57.8^{a}	0.72^{f}	12.3^{cd}	46.3^{a}	70.4^{a}
2	66.9^{a}	66.3^{a}	58.3^{a}	0.96^{de}	13.0^{abc}	46.6^{a}	69.5^{bc}
3	65.4^{bc}	64.9^{bc}	57.5^{ab}	0.86^{ef}	12.1^{d}	45.4^{ab}	69.4^{bc}
4	63.5^{e}	62.8^{d}	54.8^{d}	1.05^{cd}	13.7^{a}	43.1^{d}	68.0^{d}
5	65.2^{bc}	64.5^{bc}	57.1^{ab}	1.23^{ab}	12.4^{cd}	43.8^{cd}	67.2^{de}
6	64.9^{bcd}	64.4^{bc}	56.1^{bc}	0.84^{ef}	13.5^{ab}	43.8^{cd}	67.5^{de}
7	64.3^{cde}	63.7^{cd}	55.5^{cd}	1.04^{cd}	13.7^{a}	43.0^{d}	66.9^{e}
8	65.0^{bcd}	64.2^{bc}	56.2^{bc}	1.17^{bc}	13.4^{ab}	44.7^{bc}	68.9^{c}
9	63.8^{de}	63.0^{d}	55.5^{cd}	1.31^{a}	13.0^{abc}	44.3^{bc}	69.4^{bc}
10	63.6^{e}	62.9^{d}	55.5^{cd}	0.97^{de}	12.7^{bcd}	44.3^{bc}	69.7^{ab}
SEM	0.6	0.5	0.6	0.06	0.4	0.5	0.3

[a-f]Means within a column with different superscripts differ significantly ($p \leq 0.05$).

[1]For fresh and set weight n = 150 eggs/strain, number of eggs transferred and hatched varied by strain.

[2]Percentage data expressed as a percentage of fresh egg weight.

Table 2-6. Comparison of hatch weight and internal organ weights from ten broiler breeder strains processed at hatch[1]

Strain	Hatch weight (g)	Chick length (mm)	Shank Length (mm)	Carcass weight[2] (g)	Carcass weight[2] %[3]	Wet residual yolk weight (g)	Wet residual yolk weight %[3]	Breast muscle weight (g)	Breast muscle weight %[3]	Liver weight (g)	Liver weight %[3]	Heart weight (g)	Heart weight %[3]
1	46.5^{a}	183.7^{ab}	29.7^{ab}	34.9^{bc}	86.5^{e}	5.50^{a}	13.5^{a}	0.58^{a}	1.24^{abc}	1.19^{abc}	2.56^{c}	0.37^{a}	0.799^{abcd}
2	46.7^{a}	173.9^{e}	29.1^{cd}	36.2^{a}	87.2^{e}	5.35^{a}	12.8^{ab}	0.59^{a}	1.27^{ab}	1.10^{cd}	2.37^{e}	0.37^{a}	0.783^{bcde}
3	45.7^{ab}	173.0^{e}	28.5^{de}	35.4^{ab}	87.5^{de}	5.14^{ab}	12.5^{abc}	0.53^{abc}	1.15^{bcd}	1.19^{abc}	2.61^{cd}	0.36^{a}	0.802^{abcd}
4	44.4^{bcd}	185.9^{a}	28.6^{d}	35.1^{ab}	89.0^{bc}	4.40^{c}	11.0^{de}	0.57^{a}	1.29^{a}	1.15^{bcd}	2.59^{cd}	0.35^{ab}	0.800^{abcd}
5	43.6^{cd}	179.8^{d}	29.0^{cd}	35.1^{ab}	90.6^{a}	3.72^{d}	9.44^{f}	0.50^{bc}	1.14^{cd}	1.24^{a}	2.84^{a}	0.36^{a}	0.827^{ab}
6	43.8^{cd}	184.8^{ab}	28.0^{e}	35.6^{ab}	90.8^{a}	3.67^{d}	9.24^{f}	0.55^{ab}	1.24^{abc}	1.23^{a}	2.80^{ab}	0.38^{a}	0.882^{a}
7	43.2^{d}	184.9^{a}	28.0^{e}	34.0^{cd}	90.3^{ab}	3.73^{d}	9.73^{ef}	0.47^{c}	1.08^{d}	1.22^{ab}	2.83^{ab}	0.35^{abc}	0.821^{abc}
8	44.9^{bc}	181.2^{cd}	29.8^{a}	35.2^{ab}	87.7^{cde}	4.99^{abc}	12.3^{abc}	0.57^{a}	1.23^{abc}	1.14^{cd}	2.54^{cd}	0.32^{d}	0.704^{e}
9	43.7^{cd}	184.6^{ab}	29.0^{cd}	33.5^{d}	88.4^{cde}	4.46^{bc}	11.6^{bcd}	0.48^{c}	1.09^{d}	1.09^{d}	2.51^{de}	0.32^{bcd}	0.749^{cde}
10	44.2^{bcd}	182.4^{bc}	29.3^{bc}	34.6^{bc}	88.6^{cd}	4.50^{bc}	11.4^{cd}	0.58^{a}	1.31^{a}	1.19^{abc}	2.69^{bc}	0.32^{cd}	0.730^{de}
SEM	0.7	1.1	0.2	0.5	0.6	0.27	0.59	0.03	0.05	0.03	0.07	0.01	0.004

[a-f]Means within a column with different superscripts differ significantly ($p \leq 0.05$).

[1]For all variables measured n = 50 chicks/strain.

[2]Carcass weighed after the yolk sac had been dissected out.

[3]All percentage data expressed as a percentage of hatch weight.

Table 2-7. Comparison of growth rate and external morphology for chicks processed at 14 d[1]

Strain	7 d BW (g)	14 d BW (g)	% BW gain (0-14 d)[2]	Length 14 d (cm)[3]	Shank 14 d (cm)[4]	Keel 14 d (cm)[5]	Breast muscle weight (g)	Breast muscle weight (%)[6]	Liver weight (g)	Liver weight (%)[6]	Heart weight (g)	Heart weight (%)[6]	Residual yolk weight (g)
1	144.1^{a}	398.3^{a}	765.4^{a}	32.8^{a}	5.62^{a}	7.19^{a}	51.0^{a}	12.8^{a}	15.5^{a}	3.90^{bcd}	3.30^{a}	0.831^{ab}	0.400^{a}
2	118.2^{bc}	317.5^{cd}	591.9^{de}	31.4^{cd}	5.21^{cd}	6.53^{ef}	35.8^{bcd}	11.2^{cd}	12.4^{b}	3.91^{bc}	2.49^{bc}	0.784^{bc}	0.096^{b}
3	119.1^{bc}	300.7^{de}	567.0^{ef}	30.7^{e}	5.08^{de}	6.57^{def}	29.8^{fg}	9.83^{g}	11.4^{c}	3.80^{bcde}	2.50^{bc}	0.833^{ab}	0.259^{ab}
4	113.0^{cd}	304.5^{d}	615.3^{cd}	31.3^{d}	5.20^{cd}	6.68^{de}	33.3^{cde}	10.9^{de}	11.3^{c}	3.70^{de}	2.39^{cd}	0.785^{bc}	0.053^{b}
5	106.0^{e}	284.3^{ef}	545.7^{fg}	30.5^{e}	5.02^{e}	6.38^{fg}	33.4^{cde}	11.6^{bc}	10.4^{d}	3.65^{e}	2.39^{cd}	0.844^{a}	0.159^{b}
6	99.0^{f}	273.4^{f}	518.0^{g}	29.9^{f}	4.89^{f}	6.31^{g}	32.7^{def}	11.8^{b}	10.1^{d}	3.71^{cde}	2.23^{d}	0.826^{ab}	0.026^{b}
7	107.1^{de}	301.3^{de}	598.7^{de}	31.0^{de}	5.10^{de}	6.47^{fg}	31.4^{efg}	10.3^{fg}	11.1^{c}	3.72^{cde}	2.43^{bc}	0.811^{abc}	0.052^{b}
8	122.5^{b}	342.0^{b}	669.8^{b}	32.0^{b}	5.36^{b}	7.01^{b}	38.6^{b}	11.2^{cd}	12.9^{b}	3.78^{bcde}	2.59^{b}	0.765^{cd}	0.181^{b}
9	122.8^{b}	331.6^{bc}	641.0^{bc}	31.8^{bc}	5.26^{bc}	6.88^{bc}	35.9^{bc}	10.7^{ef}	12.9^{b}	3.95^{b}	2.55^{bc}	0.775^{bcd}	0.215^{ab}
10	113.1^{cd}	306.0^{d}	593.2^{de}	31.0^{de}	5.10^{de}	6.77^{cd}	29.6^{g}	9.59^{g}	12.7^{b}	4.17^{a}	2.23^{d}	0.731^{d}	0.146^{b}
SEM	3.1	8.5	19.0	0.2	0.6	0.9	0.2	0.22	0.4	0.09	0.09	0.024	0.104

$^{a-g}$Means within a column with different superscripts differ significantly ($p \leq 0.05$).

[1]For all variables measured n = 50 chicks/strain.

[2]Percantage data was calculated based on hatch weight values.

[3]Measured from tip of bird's beak to the end of the middle toe (not including the nail).

[4]Measured from the top of the hock joint to the bottom of the footpad.

[5]Measured from the hypocleido-clavical joint to the caudal end of the sternum.

[6]Percentage data expressed as a percentage of 14 d processing weight.

Table 2-8. Correlation coefficients for egg weight and egg composition as related to fresh egg weight from the 10 strains pooled

Variable	Albumen weight	Albumen height	Yolk weight	Shell weight	Shell thickness
Fresh egg weight	0.84074 0.0001	0.09397 0.0355	0.48028 0.0001	0.45323 0.0001	0.02122 0.6342
Albumen weight		0.17967 0.0001	0.01246 0.7859	0.32945 0.0001	0.03806 0.4064
Albumen height			0.06939 0.1302	0.04772 0.0001	0.12608 0.0047
Yolk weight				0.17169 0.0002	0.06900 0.1320
Shell weight					0.78390 0.0001

Table 2-9. Correlation coefficients for hatch weight and composition as related to fresh egg weight from the 10 strains pooled

Variable	Hatch weight	Wet residual yolk weight	Dry residual yolk weight	Abdomen score	Wet carcass weight	Dry carcass weight
Fresh egg weight	0.86745 0.0001	0.50464 0.0001	0.44686 0.0001	0.44544 0.0001	0.79133 0.0001	0.55792 0.0001
Hatch weight		0.66511 0.0001	0.61329 0.0001	0.52349 0.0001	0.83413 0.0001	0.44397 0.0001
Wet residual yolk weight			0.96610 0.0001	0.50378 0.0001	0.26201 0.0001	0.09831 0.0384
Dry residual yolk weight				0.47352 0.0001	0.19116 0.0001	0.09890 0.0372
Abdomen score					0.33675 0.0001	0.12704 0.0074
Wet carcass weight						0.67686 0.0001

Table 2-10. Range in variability of traits examined for the ten strains of broiler breeder eggs and chicks

Trait	CV Low	CV High
Fresh egg weight	5.9% (S8)[1]	8.1% (S7)
Set egg weight	5.9% (S8)	8.0% (S7)
Transfer egg weight	6.0% (S8)	8.7% (S6 & S7)
Chick weight	7.1% (S8)	9.5% (S7)
Abdomen score	16.6% (S4)	28.4% (S1)
Wet residual yolk weight	25.9% (S2)	42.5% (S7)
% Wet residual yolk	22.5% (S2)	34.9% (S7)
Dry residual yolk weight	25.8% (S2)	43.8% (S7)
Wet carcass weight	6.3% (S8)	8.6% (S7)
Dry carcass weight	6.2% (S8 & S10)	10.9% (S3)

[1]Strain are in brackets following the CV values

3.0 RELATIONSHIP BETWEEN CHICK CONFORMATION AND QUALITY MEASURES WITH EARLY GROWTH TRAITS IN MALES OF EIGHT SELECTED, PURE, OR COMMERCIAL BROILER BREEDER STRAINS[2]

3.1 INTRODUCTION

Since 1960, the number of days to market for broilers has decreased by approximately 1 d/yr (Nir and Levanon, 1993). Since the first week following hatch currently represents nearly 20% of a broilers life, growth in the first few days or even hours is becoming an essential component of the efficient achievement of market BW. During the first 2 wk of incubation, carbohydrate and protein metabolism predominate (Peebles et al., 1999), whereas during the last week, the chick utilizes lipids from the yolk sac as an energy substrate for growth (Nobel and Cocchi, 1990). The yolk has been estimated to supply 90% of the total caloric needs of a chicken embryo (Freeman and Vince, 1974). Chicks do not have the ability to properly utilize dietary lipids at hatch (Escribano et al., 1988). During the first 2 wk, as this ability develops (Carew et al., 1972), limited bile salts are a primary cause of inadequate micellar solubilization of dietary lipids (Gomez and Poulin, 1974).

A large proportion of lipid (2 g) is transferred to the chick embryo between 19 and 21 d of incubation (Ding and Lilburn, 1996). When broilers are provided with a carbohydrate diet they must switch from utilizing yolk solids to digesting and absorbing carbohydrates. This transition from yolk absorption to one of utilizing carbohydrates is often difficult and may explain why mortality is often high in the first week (Applegate, 2002).

---

[2] A version of this chapter has been published. Wolanski et al. 2006. Poultry Science. 85:1490-1497.

Research reported by Tona et al. (2003a) has investigated chick quality as evaluated by several qualitative characteristics for newly hatched chicks. Chicks scoring 100 had a significantly better relative growth rate than chicks that received any lower score. Two of their eight criteria relate to evaluation of the residual yolk of a chick, illustrating the importance of assessing yolk reserve at hatch. Residual yolk mass is extremely variable at hatch and various estimates by researchers have ranged from 8 g or 20-25% of a chick's BW (Noy and Sklan, 1996), 7.9 g or 16.8% (Chamblee et al., 1992) to 6.6 g or 15.5% (Murakami et al., 1992).

The residual yolk contained in the chick declines from hatch and is negligible by 11 d of age (Nitsan et al., 1995). However, the initial residual yolk mass can be affected by initial egg yolk size, incubation conditions, and time of hatch (Tona et al., 2003b). Also there are genotypic effects on incubation length (Crittenden and Bohren, 1961; Siegel et al., 1968; Suarez et al., 1997). Strains differing in selection criteria also have slightly differing metabolic strategies during incubation and hatch (O'Dea et al., 2004).

Residual yolk sac weight and composition is affected by many factors such as: age of dam, egg storage, incubation conditions, and egg size. However, information on yolk sac content over a wide range of genotypes is lacking. The objective of this study was to survey a broad range of genotypes from one breeding company (both pure lines and commercial lines) for relative size of the yolk sac, breast weight, carcass weight and chick body length in male broiler breeder chicks. The potential relationship between residual yolk and frame size on 2 wk BW, chick body length, and breast muscle fleshing was also assessed.

3.2 MATERIALS AND METHODS

In this study, eggs from eight broiler breeder genotypes (Table 3-1) were obtained from a commercial breeder[3] and then shipped to the University of Alberta. Eggs were obtained from hens with as narrow a range in age as possible to reduce the potential impact of hen age on residual yolk sac. Eggs were placed in a 5,000 egg capacity incubator[4] 9 d after being laid. Chicks were vent sexed at hatch and only males were used in this study. Each chick was neck tagged[5] and weighed. Subsequently, chicks were subjected to a shank length measurement of the tibia tarsus from the top of the hock joint to the bottom of the footpad. Also a bird length measurement from the tip of the beak to the end of the middle toe with the chick's dorsal surface extended over a ruler was measured. Navel condition of each chick was evaluated and the incidence of navel imperfections such as a navel button (slight opening of the navel) or navel wick (residual yolk membrane attached to navel) was recorded. The abdomen of each chick was manually palpated by a single trained individual to estimate the yolk reserves. A 3-point scale was used, where a score of 1 represented a chick with very little residual yolk, a score of 2 denoted a chick with an average amount of residual yolk, and a score of 3 equated to a chick that had a grossly distended abdomen.

A total of 50 males per strain were randomly selected to be processed on d 0. These chicks were killed by cervical dislocation and the breast muscle (*P. major and P. minor*) and the residual yolk sac were dissected from each chick. The yolk-free carcass weight was determined after the residual yolk sac had been removed. Residual yolk

---

[3]Aviagen North America, 5015 Bradford Drive, Huntsville, AL, 35805.
[4]Jamesway Incubator Company Inc., Cambridge, ON, Canada.
[5]Heartland Animal Health Inc. Fair Play, MO, 65649.

weight and a carcass weight were obtained immediately after dissection. The chick carcasses and the residual yolk sacs were then placed on individual, 5 cm diameter aluminum trays and oven dried at 60 C for 4 d and re-weighed to obtain a dry weight.

An additional 60 males per strain were randomly selected at hatch to be grown-out for a 2 wk period. On the day of hatch, chick BW, bird length, shank length, abdomen score, and navel condition were recorded. Approximately 10 h after hatching the birds were randomly placed in one of two adjacent pens (2.32 m X 5.49 m) (240 birds/pen), with each strain equally represented in the pens. The chicks were reared on a broiler starter diet (Table 3-2) with ad libitum access to feed and water with a photoperiod of 23 L and 1 D. At 2 wk of age, 50 birds per strain were randomly selected and the BW, shank length, and chick body length were measured. Also the length of the keel bone was measured from the hypocleido-clavical joint to the caudal end of the sternum with digital calipers while the bird was held horizontally (ventral side up). These birds were then killed and dissected to determine breast muscle weight and characterize the presence or absence of residual yolk. The residual yolk sacs were weighed both fresh and after being dried for 4 d at 60 C.

3.2.1 Statistical Analysis

Data were analyzed as a one-way ANOVA using the GLM procedures of SAS and means were separated using the PDIFF *t*-test procedure (SAS System, 2002). Pearson correlation coefficients were calculated between means of interest. The bird was the experimental unit for measurements taken at hatch. The pen was the experimental unit for growth traits as well as conformation and carcass traits recorded at 14 d of age. Significance was assessed at a $P<0.05$.

3.3 RESULTS AND DISCUSSION

3.3.1 Day 0 Chicks

The mean hatch BW, carcass weight, residual yolk sac weight, and breast muscle weight for each of the eight strains are shown in Table 3-3. Chicks from the pure line strains generally weighed more than the commercial chicks did. Strains S1 (40.8 g), S2 (40.6 g), and S4 (41.1 g) had the greatest hatch weight while S6 (37.2 g) and S7 (37.2 g) had the lowest hatching weight. The differences observed in hatch weight may have been influenced by initial egg size. While initial egg weight was not recorded in this trial, females originating from the same hatch produced between 105 (S1) and 163(S6) eggs in total by 56 wk of age (Rustad et al., 2005), with the heavily growth-selected, S1 hens producing a larger hatching egg. In a subsequent trial, eggs from commercial lines that were 46 to 57 wk of age weighed 64.4 g compared to 65.7 g in the pure lines (Wolanski, unpublished data). Resulting chick weights were 2.5 g higher, on average, in the pure lines compared to the commercial lines. In the current study, the contrast between chick weights of the pure lines and commercial lines common to both studies indicates a 2.4 g difference in chick weight within the pure lines (Table 3-3). Although Wolanski (unpublished data) used older hens, the resulting chick weight differences were comparable to those in the current study, demonstrating that the range in initial egg weight is likely also relevant for the current study. Differences in rate of lay among the strains tested likely contributed to differences reported in initial egg weight (Wolanski, unpublished data), with the pure lines producing fewer eggs (Rustad et al., 2005). Birds which lay fewer eggs tend to have a higher incidence of first of sequence eggs which will generally have a larger yolk (Robinson et al., 1991). Bray and Iton (1974), Silversides and Scott (2001), Tona et al., (2004b) have shown that egg weight can have a significant

influence on hatch weight, although the subsequent relationship between egg weight and 42 d BW is poor.

In the current study, although hatch weights from S1 and S4 were similar, there was a significant difference in wet carcass weight (chick with yolk sac removed) with S1 chicks having a larger yolk-free carcass (Table 3-3). The differences observed in carcass weight between these two strains may be linked to the major selection criteria used in developing these divergent genotypes (Table 3-1). Tona et al. (2004a) found differences in heat production in three lines of broiler offspring suggesting that the embryos had differential metabolic rates. Moreover they reported that chicks from the heavy line (commercial high yielding line) had the highest heat production, followed by the experimental line (selection on growth and reproduction), with the label line last (selected for slow growth and high reproductive performance). Therefore some of the difference in hatch weight may be linked to differential metabolic rates in the eight strains observed in this study.

In terms of yolk-free carcass weight, the pure line S2 chicks had the greatest amount of body reserves (35.6 g) (Table 3-3). This yolk-free mass represented 87.7% of the chicks initial hatch weight. In contrast S4 (heavily breast selected strain less emphasis on growth) had one of the highest hatch weights, yet it had one of the numerically lowest yolk-free carcass weights (33.2 g). The percentage of yolk-free carcass in this strain was only 80.8%. The fact that S4 was a heavily breast selected line may partially explain why it had the least amount of carcass reserves at hatch. Current studies suggest that high breast yield strains have a higher metabolic rate and consequently may need to be managed differently in the incubator in order to effectively

dissipate excess heat and $C0_2$ (O'Dea et al., 2004). If incubator and hatcher conditions are sub-optimal for these newly developed strains the resulting chicks may be of poorer quality (ie larger yolk sacs and less carcass reserves). The eggs of the current study were incubated according to current industry practices. The incubator was less than half-full, reducing the impact of impeded heat exchange with the air. Since the hatch was pulled at the same time for all strains, differences in incubation length requirements among strains could conceivably have affected traits such as chick dehydration at this time. However, hematocrit analysis of sample chicks from each strain demonstrated no apparent impact on this trait (Wolanski, unpublished data). The S5 chicks had a yolk-free carcass weight of 34.4 g while two similar commercial products (S6 and S7), which have slightly more emphasis on breast meat yield, had significantly less carcass reserves at hatch (32.6 and 32.9 g, respectively) (Table 3-3).

Tona et al. (2004a) suggested that hatching BW alone may not accurately describe the quality of a chick so instead they designed a qualitative scoring system that evaluated several parameters at hatch to better quantify chick quality. Although hatch weight can be used as a measure of chick quality it is often misleading because hatch weight also includes yolk residue that is internalized within the abdomen of a chick. The mass of the residual yolk in newly hatched chicks is extremely variable and in this study ranged from 0.8 to 10.6 g in individual chicks (mean = 4.3 g; 11% of chick weight) (Table 3-3). Tona et al. (2003a) examined the height and consistency of the abdomen of newly hatched chicks. Yolk residue usually constitutes about 10-12% of a chick's BW at hatch (Nitsan et al., 1991; Murkami et al., 1988, 1992). Whereas many of the recent studies indicate higher residual yolk values than those of the current study, Bierer and Eleazer (1965)

found that the average residual yolk weight of newly hatched chicks was 5.4 g, although initial chick weight was not reported.

The manual palpation scores (range of 1-3) did not differ between the strains. However, with a larger scale (1-5) it may be possible to discern strain differences. Strain 1 and S4 had 5.7 and 5.8 g of residual yolk, respectively, at the time of hatch (Table 3-3). In contrast, S6 and S7 (commercial strains) only possessed 3.1 and 3.0 g of residual yolk respectively. The dried yolk sac weight for S1 and S4 were 3.0 and 3.1 g of unutilized yolk solids respectively, which was equal to the wet weight for the commercial lines, S6 and S7. The dry weight of S6 and S7 were 1.7 and 1.5 g respectively. From this evidence it is apparent that the commercial strains have less yolk reserves to utilize. The commercial strains may have been more efficient at utilizing yolk solids or the initial yolk size of these eggs was smaller than the other strains examined. Broiler breeder strains, S5, S6, and S7, were the commercial lines, with yolk reserves at hatch being 3.8, 3.1, 3.0 g, respectively (Table 3-3). Incubation conditions appear well suited to these commercially important strains, as indicated by their low residual yolk levels at hatch.

The larger, pure line chicks of strains S1 to S4 carried more breast muscle at hatch than the commercial and experimental strains (S5 to S8) (Table 3-3). Even when compared relative to BW, breast muscle of the S2 chicks accounted for 1.4% of chick BW compared to 1.1% in S6 and S8. Research by Lilburn and Nestor (1991) have demonstrated that at hatch the *P. major* weight for rapid growth selected turkeys was significantly greater as compared with a similar unselected strain. More recently, Liu et al. (2004) reported differences in breast muscle weights at 16 d of embryonic development, and the magnitude of the line differences generally increased through 16

wk post-hatch. Differences in breast muscling at hatch were believed to be the result of increased proliferation and differentiation of myoblasts during embryogenesis (Liu et al., 2004).

Day 0 body length ranged from 185 mm in the pure line, S3 chicks to 194 mm in commercial, S5 chicks at the time of hatch (Table 3-4). Strain 4 had a compact frame size with a relatively short body length of 188 mm and shank length of 27.2 mm. This could be the direct result of increased selection for breast muscle yield in this line. A study by Msoffe et al. (2001) reported a positive correlation between both body length ($r = 0.96$) and shank length ($r = 0.96$) with adult BW in the scavenging local chickens of Tanzania. Therefore at hatch, measuring body length and shank length may be a useful tool to identify early growth potential based on initial frame size rather than using hatch BW as a sole predictor of growth potential. Embryo development can be expressed in terms of embryo length (Hill, 2001).

3.3.2 Day 14 Processed Chicks

In the 14 d processed chicks at hatch, the chick body length measurement ranged from 182 mm in S6 to 191 mm in S1 (Table 3-5). At 14 d of age S1 maintained the longest body length of 341 mm and S6 had a body length of 329 mm. By 14 d of age S4 had the shortest body length (314 mm) presumably related to the selection for specific fleshing characteristics in this genotype.

By 14 d of age, the shank length of the heavily growth selected S1 chicks was 58 mm compared to the opposite extreme of 52 mm in the stocky, S4 breast yield line (Table 3-5). The external morphometrics of these eight strains continually showed that S1 had the longest shank and body length while S4 had the shortest. The same

relationship was evident for keel length. Strain 1 chicks had a keel length of 68 mm and S4 chicks had a keel length of 58 mm. Although the percentage breast muscle deposition between these two strains was not significantly different S4, appears to have accreted breast muscle in a different manner (wider chest girth) than S1 which deposits breast muscle along the length of its keel.

At the time of hatch, S1 chicks had almost a 4 g advantage in BW compared to S6 and S7 chicks (Table 3-3). By 14 d of age, S1 chicks had an average BW of 427 g, which was almost 100 g greater than some other strains (S3, S4, S6, and S7). In terms of absolute weight gains within the first 2 wk, S1 gained 386 g while S4 had only gained 264 g. The fact that S4 grew more slowly may be attributed to the fact that it has a different genetic potential for growth. Possibly some of this difference may be attributed to the fact that S4 was shown to have a poorer utilization of yolk (Table 3-2). Murakami et al. (1992) compared deutectomized and intact chicks and found that there was a 2 d delay in growth of the deutectomized chicks which lead to the conclusion that yolk lipids in the newly-hatched chick have a crucial role in the initiation of growth. It has been shown that chickens selected for rapid growth posses a higher metabolic rate than unselected birds (Jorgensen et al., 1990; Buys et al., 1998). These same birds may posses a higher metabolic rate while inside the egg as long as factors such as energy substrate, oxygen, or carbon dioxide were not limiting or in excess. Tona et al. (2004a) found that chicks with higher metabolic rates scored higher on the chick quality scale and had better 7 d growth performance.

Tona et al. (2004b) found that the average daily gain of a broiler can range from 15 g to 91 g. In the same study it was found that the correlation between quality score

and 1 day-old BW was low which supports that both parameters are different and independent. Tona et al. (2004b) reported that hatch weight ultimately did not correlate with 42 d BW. It has been demonstrated by Merritt and Gowe (1965) and Moran (1990) that d old chick BW and egg weight have a strong positive correlation. However, the relationship between relative growth rate and egg weight is less clear which suggests that other factors (appetite, yolk utilization, water consumption) rather than just egg weight and d old chick weight impact a chick's growth potential. Feed intake rapidly becomes a more important indicator of final BW than initial chick weight (Pinchasov, 1991). When evaluating chick quality at hatch, parameters such as residual yolk reserve, chick length measures, and chick activity may be useful in evaluating chick quality rather than relying on hatch weight alone as the sole measure of chick quality.

At 14 d of age, S1 had 52 g of breast muscle which constituted 12.0% of the birds total BW (Table 3-6). In contrast S3 had only 31 g of breast muscle (9.4% breast muscle). Strain 4 and S8, which are the heavily breast selected strains, did not have the largest breast weight. However, their relative percent breast muscle (12.0 and 12.6%) was similar to S1. Among the three commercial strains (S5, S6, and S7), as the selection pressure increased for white meat yield, there was a trend toward greater breast muscle percentage, with the strains having 11.1, 11.3, and 11.7% breast muscle respectively.

By 14 d of age all of the strains had very little residual yolk remaining. However, on average S1 chicks still had 0.4 g of residual yolk, which was significantly greater than all the strains except S4 and S8. This is similar to the trend at hatch where S1 and S4 had the greatest yolk reserves with S8 having slightly less yolk reserves.

3.3.3 Correlations

The manual palpation scores were correlated with actual residual yolk sac weights ($r = 0.50$). With a larger scale and more fine-tuning this abdomen score may allow for an accurate estimate of chick yolk reserves at hatch. Body weight was a key factor in significant correlations found at hatch (Table 3-7). There was a significant correlation between breast muscle weight and hatch weight across all strains examined ($r = 0.46$). The use of length measurements such as chick body length and shank length at hatch correlated with a chick's wet carcass reserves being ($r = 0.60$ and $r = 0.56$). Therefore these measurements at hatch may elucidate the amount of body reserves that have been synthesized during the incubation period.

Correlations of hatch and 14 d values reveal the strength of the relationship between hatch traits and 14 d BW (Table 3-8). It was found that both shank length ($r = 0.43$) and chick body length ($r = 0.38$) correlated more strongly with 14 d body weight than did initial hatch weight ($r = 0.34$). This suggests that the measurement of shank length may provide the most accurate measure of growth potential when compared to the predictive value of either chick weight or chick body length. The inferior correlation resulting from the chick weight value with 14 d BW is partially confounded by the variation in the amount of internalized residual yolk mass.

Assessing chick quality is difficult and by no means should chick weight be the sole measure of a quality chick. It was found that both body length and shank length correlate better with 14 d BW than hatch weight. These length measurements may provide a measure of day old frame size and therefore could allow us to predict 14 d BW. Chick quality at the time of hatch should include many factors such as hatch weight, navel

condition, an estimation of yolk reserves, chick body length, activity of chick, and down condition. At hatch differences in chick wt, breast wt, and residual yolk were apparent across the eight strains examined in this study. The heavily growth-selected S1 chicks consistently displayed superior BW and breast muscling and also had the longest length measurements. The S4 chicks, from a highly breast selected strain, had a low BW and a carried a high proportion of breast muscle by 14 d of age. The residual yolk reserves in S1 and S4 were significantly higher than the commercial products (S5, S6, and S7). These strain differences may be attributed to genotypic variation, differences in egg size, or a varying response to a common incubation protocol. Therefore it may be necessary to refine incubation practices for new high yielding strains so that yolk utilization is optimized resulting in improved chick quality.

3.5 REFERENCES

Applegate, T. J. 2002. Reproductive maturity of turkey hens; egg composition, embryonic growth and hatchling transition. Avian Poult. Biol. Rev.13:31-41.

Bierer, B. W., and T. H. Eleazer. 1965. Effects of feed and water deprivation on yolk utilization in chicks. Poult. Sci. 44:1608-1609.

Bray, D. F., and E. L. Iton. 1962. The effect of egg weight on strain differences in embryonic and post-embryonic growth in the domestic fowl. Br. Poult. Sci. 15:175-187.

Buys, N., E. Dewil, E. Gonzales, and E. Decuypere. 1998. Different $C0_2$ levels during incubation interact with hatching time and ascites susceptibility in two broiler lines selected for different growth rate. Avian Pathol. 27:605-612.

Carew, L. B, Jr., M. A. Jr. Machemer, R. W. Sharp, and D. C. Foss. 1972. Fat absorption by the very young chick. Poult. Sci. 51:738-742.

Chamblee, T. N., J. D. Brake, C. D. Schultz, and J. P. Thaxton. 1992. Yolk sac absorption and the initiation of growth in broilers. Poult. Sci. 71:1811-1816.

Crittenden, L. B., and B. B. Bohren. 1961. The genetic and environmental effect of hatching time, egg weight, and holding time on hatchability. Poult. Sci. 40:1736-1750.

Ding, S. T., and M. S. Lilburn. 1996. Characterization of changes in yolk sac and liver lipids during embryonic and early posthatch development of turkey poults. Poult. Sci. 75:478-483.

Escribano, F., B. E. Rahn, and J. L. Sell. 1988. Development of lipase activity in yolk membrane and pancreas of young turkeys. Poult. Sci. 67:1089-1097.

Freeman, B. M., and M. A. Vince. 1974. Page 163 in: Development of Avian Embryo. Chapman and Hall, London, UK.

Gomez, M. X., and D. Poulin. 1974. Influence of cholic acid on the utilization of fats in the growing chicken. Poult. Sci. 55:2189-2195.

Harvey, J. D., D. B. Parrish, and P. E. Sandford. 1955. Improvements in the techniques of deutectomy of newly hatched chicks and the effects of the operation on their subsequent development. Poult. Sci. 34:3-8.

Hill, D. 2001. Chick length uniformity profiles as a field measurement of chick quality? Avian Poult. Biol. Rev. 12:188.

Jorgensen, H., P. Sorensen, and B. O. Eggum. 1990. Protein and energy metabolism in broiler chickens selected for either body weight gain or feed efficiency. Br. Poult. Sci. 31:517-524.

Lilburn, M. S., and K. E. Nestor. 1991. Body weight and carcass development in different lines of turkeys. Poult. Sci. 70:2223-2231.

Liu, X., K. E. Nestor, and S. G. Velleman. 2004. The influence of selection for increased body weight and sex on pectoralis major muscle weight during the embryonic and post-hatch periods. Poult. Sci. 83:1089-1092.

Merritt, E. S., and R. S. Gowe. 1965. Post embryonic growth in relation to egg weight. Poult. Sci. 44:477-480.

Moran, E. T., Jr. 1990. Effects of egg weight, glucose administration at hatch, and delayed access to feed and water on the poult at 2 weeks of age. Poult. Sci. 69:1718-1723.

Msoffe, P. L. M., U. M. Minga, J. E. Olsen, M. G. S. Yongolo, H. R. Juul-Madsen, P. S. Gwakisa, M. M. A. Mtambo. 2001. Phenotypes including immunocompetence in scavenging local chicken ecotypes in Tanzania. Trop. Anim. H. and Prod. 33:341-354.

Murakami, H., Y. Akiba, M. Horiguchi. 1988. Energy and protein utilization in newly-hatched broiler chicks -Studies on the early nutrition of poultry. Jpn. J. Zootech. Sci. 59:890-895.

Murakami, H., Y. Akiba, and M. Horiguchi. 1992. Growth and utilization of nutrients in newly-hatched chicks with or without removal of residual yolk. Growth Dev. Aging 56:75-84.

Nir, I., and M. Levanon. 1993. Effect of post-hatch holding time on performance and on residual yolk and liver composition. Poult. Sci. 72:1994-1997.

Nitsan, Z., E. A. Dunnington, and P. B. Siegel. 1991. Organ growth and digestive enzyme levels to 15 days of age in lines of chickens differing in body weight. Poult. Sci. 70:2040-2048.

Nitsan, Z., I. Turro-Vincent, G. Lui, E. A. Dunnington, P. B. Siegel. 1995. Intubation of weight-selected chicks with soybean oil or residual yolk: effect on early growth and development. Poult. Sci. 74:925-936.

Noble, R. C., and M. Cocchi. 1990. Lipid metabolism and the neonatal chicken. Prod. Lipid Res. 29:107-140.

Noy, Y., Z. Uni, and D. Sklan. 1996. Routes of yolk utilization in the newly-hatched chick. Br. Poult. Sci. 37:987-996.

O'Dea, E. E., G. M. Fasenko, J. J. R. Feddes, F. E. Robinson, J. C. Segura, C. A. Ouellette, and J. H. van Middelkoop. 2004. Investigating the eggshell conductance and embryonic metabolism of modern and unselected domestic avian genetic strains at two flock ages. Poult. Sci. 83:2059-2070.

Pinchasov, Y. 1991. Relationship between the weight of hatching eggs and subsequent early performance of broiler chicks. Br. Poult. Sci. 32:109-115.

Peebles, D. E., L. Li, S. Miller, T. Pansky, S. Whitmarsh, M. A. Latour, and P. D. Gerard. 1999. Embryo and yolk compositional relationships in broiler hatching eggs during incubation. Poult. Sci. 78:1435-1442.

Robinson, F. E., R. T. Hardin, N. A. Robinson, B. J. Williams. 1991. The influence of egg sequence position on fertility, embryo viability, and embryo weight in broiler breeders. Poult. Sci. 70:760-765.

Rustad, M. E., F. E. Robinson, R. A. Renema, M. J. Zuidhof, V. L. Carney. 2005. Effects of over feeding on sexual maturation and egg production in 8 strains of broiler breeder hens. Poult. Sci. 84(Suppl. 1):48.

SAS System (2002) SAS 9.1. Copyright (c) 2002-2003 by SAS Institute Inc., Cary, NC, USA.

Siegel, P. B., J. W. Coleman, H. B. Graves, and R. E. Phillips. 1968. Incubation period of chicken selected bi-directionally for juvenile body weight. Poult. Sci. 47:105-107.

Silversides, F. G., and T. A. Scott. 2001. Effect of storage and layer age on quality of eggs from two lines of hens. Poult. Sci. 80:1240-1245.

Suarez, M. E., H. R. Wilson, F. B. Mather, C. J. Wilcox, and B. N. Mcpherson. 1997. Effect of strain and age of the broiler breeder female on incubation time and chick weight. Poult. Sci. 76:1029-1036.

Tona, K., F. Bamelis, B. De Ketelaere, V. Bruggeman, V. M. B. Moraes, J. Buyse, O. Onagbesan, and E. Decuypere. 2003a. Effects of egg storage time on spread of hatch, chick quality, and chick juvenile growth. Poult. Sci. 82:736-741.

Tona, K., R. D. Malheiros, F. R. Bamelis, C. Careghi, V. M. B. Moraes, O. Onagbesan, E. Decuypere, and V. Bruggeman. 2003b. Effects of storage time on incubating eggs gas pressure, thyroid hormones, and corticosterone levels in embryos and on their hatching parameters. Poult. Sci. 82:840-845.

Tona, K., O. M. Onagbesan, Y. Jego, B. Kamers, E. Decuypere, and V. Bruggeman. 2004a. Comparison of embryo physiological parameters during incubation, chick quality, and growth performance of three lines of broiler breeders differing in genetic composition and growth rate. Poult. Sci. 83:507-513.

Tona, K., O. Onagbesan, B. De Ketelaere, E. Decuypere, and V. Bruggeman. 2004b. Effects of age of broiler breeders and egg storage on egg quality, hatchability, chick quality, chick weight, and chick posthatch growth to forty-two days. J. Appl. Poult. Res. 13:10-18.

TABLE 3-1. Description and the main selection criteria for the eight strains of broiler breeders

Strain	Selection criteria
S1	Growth rate, feed conversion rate, and carcass yield
S2	Undisclosed pure line
S3	Undisclosed pure line
S4	Breast yield with less emphasis on growth rate
S5	Commercial product designed for the whole bird market
S6	Commercial product designed for the deboned market
S7	Commercial product designed for increased white meat yield
S8	Experimental line

TABLE 3-2. Composition of broiler starter diet fed from day 0 to end of trial (14 d)

Ingredients	Proportion (%)
Soybean meal (48% CP)	41.19
Corn	48.00
Canola oil	4.90
Dicalcium phosphate	2.27
Calcium carbonate	1.47
Broiler premix[1]	0.50
Choline chloride premix[2]	0.50
Salt	0.49
L-lysine	0.08
DL-methionine	0.30
Vitamin E 5000 IU/KG	0.30
Calculated composition	
ME (kcal/kg)	3,100
Crude Protein	23.8

[1] Broiler premix provided per kilogram of diet; vitamin A (retinyl acetate), 10,000 IU; cholecalciferol, 2,500 IU; vitamin E (DL-α-tocopheryl acetate), 35 IU; vitamin K, 2 mg; pantothenic acid, 14 mg; riboflavin, 5.0 mg; folacin, 0.8 mg; niacin, 65 mg; thiamine, 2.0 mg; pyridoxine, 4.0 mg; vitamin B12, 0.015 mg; biotin, 0.18 mg; iodine, 0.5 mg; Mn, 70mg; Cu, 8.5 mg; Zn, 80 mg; Se, 0.1 mg; Fe, 100 mg.

[2] Provided choline chloride in the diet at a level of 100 mg/kg.

TABLE 3-3. Comparison of chick weight, wet carcass weight, wet yolk wet, dry carcass weight, and dry yolk weight and breast muscle mass at hatch for males of eight broiler breeder strains

	Hatch	Carcass weight		Residual yolk weight		Breast muscle
Strain	weight (g)	Wet[1] (g)	Dry[2] (g)	Wet (g)	Dry[2] (g)	weight (g)
S1	40.84^{a}	34.51^{b}	8.43^{ab}	5.72^{a}	3.04^{a}	0.475^{c}
S2	40.58^{a}	35.60^{a}	8.42^{ab}	4.43^{b}	2.25^{bc}	0.547^{a}
S3	38.62^{b}	33.68^{bcd}	8.21^{bc}	4.17^{bc}	2.25^{bc}	0.524^{ab}
S4	41.09^{a}	33.24^{cd}	8.17^{bc}	5.84^{a}	3.10^{a}	0.522^{ab}
S5	38.70^{b}	34.44^{b}	8.49^{a}	3.80^{c}	1.99^{c}	0.468^{d}
S6	36.91^{c}	32.60^{d}	8.35^{ab}	3.10^{d}	1.65^{d}	0.422^{e}
S7	37.21^{c}	32.91^{d}	7.96^{c}	2.96^{d}	1.48^{d}	0.448^{de}
S8	39.88^{ab}	34.05^{bc}	8.44^{ab}	4.58^{b}	2.43^{b}	0.457^{de}
SEM	0.5	0.38	0.09	0.19	0.11	0.016

[a-c]Means within a column with different superscripts differ significantly ($p \leq 0.05$).
[1]Carcass weighed after the yolk sac had been dissected out.
[2]Weighed following 4 d in a 60C drying oven.

TABLE 3-4. Comparison of external measurements at hatch of males from eight broiler breeder strains

Strain	Hatch chick length[1] (mm)	Hatch shank length[2] (mm)	BW : shank length (g/mm)	BW:chick length (g/mm)
S1	188.6^{de}	28.85^{a}	1.42^{bc}	2.17^{ab}
S2	193.2^{ab}	28.99^{a}	1.40^{bc}	2.10^{bc}
S3	185.4^{f}	27.62^{bcd}	1.40^{bc}	2.08^{c}
S4	188.0^{e}	27.24^{d}	1.51^{a}	2.19^{a}
S5	193.7^{a}	28.00^{b}	1.38^{cd}	2.00^{d}
S6	189.6^{cde}	27.59^{cd}	1.34^{e}	1.95^{d}
S7	190.5^{cd}	27.63^{bcd}	1.35^{de}	1.95^{d}
S8	191.4^{bc}	27.74^{bc}	1.44^{b}	2.08^{c}
SEM	0.8	0.14	0.02	0.02

$^{a-f}$Means within a column with different superscripts differ significantly ($p \leq 0.05$).
[1]Measured from the tip of the birds beak to the end of the middle toe (not including the nail).
[2]Measured from the top of the hock joint to the bottom of the foot pad.

TABLE 3-5. External measurements of male chicks at hatch and at 14 days of age of males from eight broiler breeder strains

Strain	Chick length[1]		Shank length[2]		14 Day keel
	Hatch (mm)	14 d (mm)	Hatch (mm)	14 d (mm)	length[3](mm)
S1	190.5^{a}	340.7^{a}	29.29^{a}	58.09^{a}	68.21^{a}
S2	189.6^{ab}	324.0^{de}	28.71^{b}	54.16^{c}	62.17^{cd}
S3	188.0^{bc}	327.3^{cde}	27.90^{de}	53.93^{c}	60.35^{de}
S4	184.2^{ef}	314.0^{f}	27.17^{f}	51.67^{d}	57.71^{f}
S5	190.0^{ab}	338.2^{ab}	28.34^{c}	57.22^{ab}	66.08^{ab}
S6	182.2^{f}	329.4^{cd}	27.70^{e}	54.00^{c}	62.01^{cd}
S7	186.4^{cd}	322.5^{e}	28.13^{cd}	53.16^{c}	59.31^{ef}
S8	185.8^{de}	333.1^{bc}	28.21^{cd}	56.41^{b}	63.84^{bc}
SEM	0.07	0.22	0.13	0.50	0.85

[a-f] Designates means and ± SEM within a column and means with different superscripts differ significantly ($p \leq 0.05$).

[1] Measured from the tip of the birds beak to the end of the middle toe (not including the nail).

[2] Measured from the top of the hock joint to the bottom of the foot pad.

[3] Measured from the hypocleido-clavical joint to the caudal end of the sternum.

TABLE 3-6. Comparison of hatch weights, 14 day body weights, BW gain, and breast muscle weight of males from eight broiler breeder strains

Strain	Hatch weight (g)	14 Day BW (g)	BW gain[1] (g)	14 Day breast muscle weight (g)	14 Day breast muscle (%)
S1	41.2[a]	427.1[a]	385.9[a]	51.8[a]	12.00[ab]
S2	39.8[b]	342.9[c]	303.0[c]	38.6[d]	11.06[d]
S3	39.1[bc]	327.7[cd]	288.6[cd]	31.3[e]	9.44[e]
S4	39.2[bc]	302.9[e]	263.7[e]	36.7[d]	11.96[b]
S5	38.5[c]	384.2[b]	345.7[b]	42.9[c]	11.14[cd]
S6	36.6[d]	339.8[c]	303.1[c]	38.6[d]	11.26[cd]
S7	36.4[d]	313.9[de]	277.4[de]	37.2[d]	11.67[bc]
S8	39.3[bc]	375.3[b]	336.0[b]	47.8[b]	12.64[a]
SEM	0.4	8.6	8.5	1.4	0.18

[a-e] Designates means and ± SEM within a column and means with different superscripts differ significantly ($p \leq 0.05$).

[1] Calculated as the 14 day BW minus the initial hatch weight for each chick.

TABLE 3-7. Correlation coefficients for early chick growth and carcass parameters of males from eight broiler breeder strains

Variable	Hatch chick length	Hatch shank length	Breast weight	Wet yolk weight	Dry yolk weight	Wet carcass weight	Dry carcass weight
Hatch weight	0.30399 0.0001	0.34589 0.0001	0.45675 0.0001	0.59937 0.0001	0.57603 0.0001	0.81459 0.0001	0.48145 0.0001
Hatch chick length		0.61067 0.0001	0.10498 0.0361	-0.27524 0.0001	-0.29251 0.0001	0.60090 0.0001	0.61298 0.0001
Hatch shank length			0.15943 0.0014	-0.04094 0.4142	-0.04759 0.3424	0.56119 0.0001	0.45296 0.0001
Breast weight				0.40371 0.0001	0.29925 0.0001	0.29059 0.0001	0.38730 0.0001
Wet yolk weight					0.98758 0.0001	0.125980 0.0117	-0.13675 0.0062
Dry yolk weight						0.10051 0.0445	-0.13578 0.0065
Wet carcass weight							0.73451 0.0001

TABLE 3-8. Correlation coefficients for total length, shank length and BW at both time of hatch and 14 days of age (keel is only reported at 14 days) from the eight strains pooled

Variable	Hatch chick length	14 Day chick length	Hatch shank length	14 Day shank length	14 Day keel length	14 Day BW	14 Day breast muscle weight
Hatch weight	0.43863 0.0001	0.29754 0.0001	0.41531 0.0001	0.28943 0.0001	0.25975 0.0001	0.34022 0.0001	0.26512 0.0001
Hatch chick length		0.47660 0.0001	0.68334 0.0001	0.42615 0.0001	0.33039 0.0001	0.38340 0.0001	0.26815 0.0001
14 Day chick length			0.46557 0.0001	0.90923 0.0001	0.81874 0.0001	0.88903 0.0001	0.79487 0.0001
Hatch shank length				0.47963 0.0001	0.39915 0.0001	0.43346 0.0001	0.35331 0.0001
14 Day shank length					0.83620 0.0001	0.90763 0.00010	0.82397 0.0001
14 Day keel length						0.84985 0.0001	0.79654 0.0001
14 Day BW							0.91684 0.0001

4.0 RELATIONSHIPS AMONG GROWTH, VARIABILITY, AND MORTALITY OF MALE BROILER BREEDERS THROUGH A 61 WEEK PRODUCTION CYCLE

4.1 INTRODUCTION

Breeder males are integral to ensuring good flock fertility from the onset of lay through to depopulation. Studies on mortality rates have reported, that in most species a higher proportion of males die compared to females, due to a variety of reasons (Fox et al., 2003; Deakin et al., 2007). One of the biggest challenges for hatching egg producers often relates to keeping mortality and culling losses of males at an acceptable level. Peak and Brake (2000), stated that male mortality represents nearly 50 % of all males placed in a breeder flock. These authors found that rearing males on a more concave growth profile reduced mortality by 8 to 11 %. With severely feed restricted birds, there is intense competition for feed resources which has implications on early BW and growth. A study by Saleh et al. (2005) showed in broilers that early feed restriction reduced both BW gains and lowered mortality. During feeding larger males may be able to use their size to obtain more feed than smaller flock mates.

Ultimately, the male contribution to flock fertility can be influenced by semen volume, concentration, and the ability to adequately inseminate hens. Various breeder management guides recommend using 8 to 9 males per 100 hens at 20 – 30 wk, however by the end of lay a ratio of 6 to 7 males per 100 hens may be adequate. During the lay period male aggression can impact fertility so management personnel need to evaluate what mating ratio produces the best results. As breeding males age they continue to grow breast muscle tissue, and excessive breast muscle deposition has been shown to negatively impact the ability of males to properly transfer semen to the hen (McGary et

al., 2003). Increased male BW toward the end of a production cycle has been associated with decreased reproductive function (Brillard and McDaniel, 1986). Various physical characteristics may influence reproductive capabilities of broiler breeder males, however adequate testes size and proper cell structure within the testes need to be present to permit semen production. Wolanski et al. (2004a) documented that in 63 wk old broiler breeder males, 6 % of males surveyed lack adequate testes size to permit semen production. Therefore in this study, relationships between male juvenile growth profile, reproductive characteristics, and liveability were of particular interest.

4.2 MATERIALS AND METHODS

A total of 530 male breeder chicks were tagged and weighed at a commercial hatchery (Lilydale Hatchery, Calgary). External morphometrics were measured for each bird to better understand individual body length dimensions. These measurements included shank length (from the joint of the tibia and femur to the base of the foot pad) and total chick length (from the tip of the beak to base of toe not including nail). Length measures were performed to evaluate their usefulness in breeder males as Wolanski et al. (2004b) has shown that length measures in broilers correlated more strongly with 6 wk BW than did hatch weight. The navel condition of each male was evaluated. Navels were characterized as navel wicks (shell membrane attached to navel), or navel buttons (opening of navel). The amount of residual yolk was estimated using a 5 point scale that has been developed and previously reported in chapters 1 and 2. In brief, a score of 1 indicated chicks with very little residual yolk present as determined by an emaciated abdomen that felt sunken and empty. A score of 5 equated to chicks which had a large residual yolk sac as indicated by a firm abdomen that felt full and mushy. After

processing the chicks they were returned to chick boxes and shipped to a breeder farm where they were reared amongst a group of 1,500 males.

The BW of the males was evaluated at hatch 4, 8, 12, 16, and 18 wk. The length measurements were performed at hatch, 8, and 16 wk of age. At 8 and 16 wk a keel measurement was used in place of the total length measurement for ease of data collection. At 18 wk (housing) the males were randomly divided between two laying complexes with 207 males placed in Barn 1 and 222 males allocated to Barn 2. There were roughly equal numbers of pullets in each barn (Barn 1 (n = 4170) and Barn 2 (n = 4191)). The males and females were integrated at 18 wk and kept on short days until 22 wk of age at which time both sexes were photo-stimulated. The lighting program had an increased day length from 8 L and 16 D during rearing to 10 L and 14 D at 23 wk. Day length was further increased by 2 h every week until a maximum day length of 14L and 10 D was reached by 25 wk.

After transfer from the rearing house to the breeder barn, birds were penned up on the slats for the first 2 or 3 d so that birds could acclimate to the water and feed systems while also properly integrating with one another. Males and females were fed in the same trough for the first 2 wk in the breeder barn. After 2 wk of feeding together, the male feed lines were lowered and males were fed separately. Birds were fed standard commercial grower diets (2,620 kcal/kg ME and 16 % CP) and breeder diets (2,660 kcal/kg ME and 16.0 % CP) which were formulated to satisfy the energy and protein requirements of growth and reproduction. This producer reared the males below the Ross BW guide recommended which may have reduced problems with female mortality and

slatting of hens. By 28 wk the average male BW was brought back to the target recommended by the breeder guide.

At 46 wk, both flocks were spiked by culling out poor quality males and adding replacement males which were of the same age. The level of spiking was to ensure that male percentages in both flocks were topped up to 8.5 to 9.0 % of female numbers. At the time of flock dispersal (61 wk) tagged males were sorted out of each barn and killed by cervical dislocation. The length of the shank and keel along with foot pad condition were characterized for each bird. Foot pad condition of male's was evaluated according to a 3 point scale reported by Wolanski et al. (2004a) where a score of 1 equated to feet with large open sores and a score of 3 indicated feet which had no ammonia burns or open lesions. Males were also scored for relative feather cover as per the methods of Renema et al. (2007). Body weight and breast muscle weight were obtained at dissection as well as a left and right testis weight.

Through the entire 61 wk, life of the flock mortality and cull males were collected and frozen so post-mortem analysis could be performed to determine the underlying causes of all mortalities. Each post-mortem case was categorized into one of four descriptions which attempted to explain the cause of death (ie. nutritional, aggression/infection, cull, or other). Birds which died of a nutrition-related cause were either dehydrated or had intestinal compaction as the post-mortem diagnosis. Aggression and infection related deaths were indicated by males which had large scratches on their backs or males which had developed a septic arthritis condition. Aggression and infection related deaths were reported together as it was impossible to identify if a male had developed the septicemia condition prior to one male aggressively dominating

another or if the septicemia occurred as a result of a male to male fight. Males which were culled out of the flock were recorded as culls. Mortalities which did not fit into the previous three categories were placed in a separate category (other).

4.2.1 Statistical Analysis

For data which was collected after 18 wk of age, each barn of males was considered the experimental unit. Data on the external measures and internal measurements of males made at 61 wk were analyzed as a One-way ANOVA analysis comparing Barn 1 with Barn 2. Birds were then sorted based on 18 wk BW into LOW, STANDARD (STD), and HIGH size groups to investigate the relationship between juvenile BW and traits at 61 wk. Birds that had BW within ± half a standard deviation of the mean were classified as STD; birds with greater than half a standard deviation below the mean were considered LOW BW birds; and males which had a BW greater than half a standard deviation above the mean were classified as HIGH BW birds. Pearson correlation analysis was completed to identify relationships between traits of interest. Subjective scores such as foot score and feather score underwent chi-squared analysis using Fischer's exact test. Significance was assessed at a P value ≤ 0.05.

4.3 RESULTS AND DISCUSSION

4.3.1 Hatch Traits of Males

The correlation between abdomen score and weight of residual yolk mass has been shown to be moderate ($r = 0.50$) (Chapters 1 and 2). The mean abdomen score in the males was 3.1 on a five point scale which equates to adequate yolk reserves. The mean hatch weight of the 530 males surveyed in this study was 42.7 g with a coefficient of variation (CV) of 7.9 % (Table 4-1). Hatch length and shank length were 181 and 29.6

mm respectively and these length measures had lower CV values being 2.8 and 3.8 % respectively. This shows that there was greater variation in hatch weight than in length measures performed at hatch, possibly because hatch weight also includes residual yolk mass which has been internalized by the chick. In Chapter 1 of this thesis, residual yolk mass was shown to be extremely variable across genotype with CV values ranging from 26 to 43 % in 10 strains of breeder chicks.

The eggs from which these breeder males hatched from were produced by a breeder flock which was 40 wk of age. It has been documented that chicks from extremely young breeders <29 wk or from aging breeders >65 wk do not perform well when compared to chicks obtained from breeders during peak or just after peak lay (Sinclair et al., 1990; Peebles et al., 1999). Chicks from young breeders have higher mortality after placement (Wyatt et al., 1985), possibly due to a lack of necessary yolk reserves. Chicks with large amounts of residual yolk have compromised navels or open navels thus predisposing hatchlings to omphalitis or early mortality (Speer, 1996). The navel closure of these males was excellent (data not shown) therefore early chick mortality was extremely low (only two chicks died during brooding). In fact, mortality for the rearing phase (0-18 wk) was extremely low at 2.8 %.

4.3.2 Frame Size

There has been little research conducted on male growth, frame size, and BW profiles of breeder males in a commercial setting, therefore the shank length and keel length were reported as descriptive data. The BW of males which were tagged at hatch was determined during rearing at 4, 8, 12, 16, and 18 wk of age (Table 4-1). These males were reared on a concave growth profile with an observed 4 wk BW of 535 g as

compared to the breeders recommended BW of 690 g. However, by 8 wk males were only 50 g lower in BW than the target recommended by the breeder. The BW of males tended to be 160 – 210 g lower than the breeder guides recommended BW at 12, 16, and 18 wk. As the males neared sexual maturity, more generous feed increases were provided to ensure that the males would achieve the target BW as recommended by the breeder guide.

The shank and keel length of the males was quantified at both 8 and 16 wk of age (Table 4-1). At 16 wk of age the males had a mean shank and keel length of 126 and 153 mm respectively. The males frame size was still developing after 16 wk because at 61 wk the shank length had increased to 143 mm (Barn 1) which was significantly larger than Barn 2 (141 mm) (Table 4-2). In terms of keel length, at 16 wk the mean value was 153 mm and at the time of flock dispersal the keel length between the barns was not significantly different being 193 and 190 mm for Barn 1 and Barn 2 respectively. The BW category had a significant impact on keel length at 61 wk ($p = 0.0178$), however shank length was not affected by BW category ($p = 0.1491$). This finding was in agreement with Ingram and Hatten, (2001) who reported that feed restriction program and age at which feed restriction was initiated impacted keel length and head width more that the effects on shank length of males. In Barn 1 the HIGH BW birds has significantly longer shanks and keels than either the STD or LOW birds (Table 4-2). In Barn 2 a similar trend was observed for keel length but the shank measurement did not appear to follow this trend.

4.3.3 Body Weight and Mortality

Table 4-2 showed that the breeder barn had a significant effect on many of the traits examined in this study. The average BW of males placed into Barn 1 was nearly 30 g lower than males placed into Barn 2 (Table 4-2). This 30 g difference in BW may have implications for the manner in which males are transferred into breeding barns from a common male rearing facility. The BW difference at housing could have been a result of larger males being caught first and transferred to Barn 2 while the remaining lighter males were allocated to Barn 1. By 61 wk, the two breeder barns had a BW difference of 187 g with Barn 1 having a mean weight of 4,999 g as compared to Barn 2 which had a mean weight of 4,812 g. The level of mortality showed that males in Barn 2 had a 51 % probability of mortality as compared to a 33 % probability of mortality in Barn 1. The breeder houses had identical slats and feeding systems with similar male percentages and both barns were free of disease yet the mortality was significantly higher in Barn 2. Although not investigated in this study, factors such as breeder house design and individual male behaviour may influence male liveability and warrant further investigation.

In Barn 1 HIGH BW males at 18 wk were still significantly heavier at 61 wk (5,301 g). However, the LOW BW and STD weight males although 500 g different at 18 wk were not significantly different from each other at 61wk being 4826 and 4870 g respectively. There number of males in each BW category was 58, 90, and 59 for the LOW, STD, and HIGH groupings at 18 wk. The BW categories were significantly different in terms of BW and varied on average 500 g from one category to the next being 2179, 2681, 3176 g. At 61 wk the number of males in each category had been reduced to

40, 64, and 38 males within the LOW, STD, and HIGH. The mortality for Barn 1, was equally distributed throughout the BW groupings with a 37, 29, 36 % rate of mortality for the LOW, STD, and HIGH categories. Interestingly the almost 1 kg range in BW which was observed at 18 wk between the initial groups had decreased. The final weights observed were 4826, 4870, and 5301 g for the LOW, STD, and HIGH. This shows that the restriction programs and competition in the breeder barn can have a major effect on influencing a breeder males final BW regardless of initial housing BW.

Barn 2 had a total of 222 males placed with 67, 95, and 60 males distributed into the LOW, STD, and HIGH categories based on 18 wk weight. The mean weights of these groups were 2178, 2655, and 3294 g respectively. Mortality in Barn 2 was significantly higher, therefore at 61 wk only 114 of the original males placed remained with 29 (LOW), 49 (STD), and 36 (HIGH). The final BW of these males was not related to the 18 wk weight as the LOW, STD, and HIGH group had weights which were not statistically different (4682, 4825, and 4930). It was interesting to note that there was still a trend toward increased BW in the HIGH group but due to high rates of mortality the standard error was much larger for Barn 2. LOW and HIGH groups for Barn 2 were approximately 200 and 400 g different than counterpart males in Barn 1, however both of the STD groups had final BW of within less than 50 g of each other.

This illustrates that factors other than initial housing weight, such as male competitive drive may also influence final BW of breeder males. Although BW category was not a significant factor in the rate of male mortality, it was noted that LOW males had a 37 % and 63 % rate of mortality for Barn 1 and Barn 2.

4.3.4 Breast Muscle and Testes Data

Breast muscle fleshing followed the trend in BW data where males from Barn 1 had numerically more breast meat (Table 4-3). This result was expected as research has shown that heavier birds produce a greater proportion of breast muscle (Marks, 1995; and Moran, 1995) and breast muscle weight has been reported to correlate strongly with final BW of breeder males (Wolanski et al., 2004a). When males were sorted based on 18 wk BW, breast muscle weight and % breast muscle at 61 wk were not significantly influenced by initial BW groupings.

The left testis and right testis were both significantly larger for males from Barn 1 compared to males from Barn 2 (Table 4-3), so total testes weight showed the same trend (26.3 vs 22.4 g respectively). Feed restriction has been shown to negatively impact absolute testes weight in breeder males (McCartney and Brown, 1980), however the fertility and hatchability were not affected. Males which had a total testes weight of less than 15 g in this study were classified as having regressed testes. When dissecting males it was observed that some males lacked the necessary threshold weight of testes for semen production. Therefore a graphic distribution was created to illustrate males which had testes that were inadequate for semen production (Figure 4-1). This phenomenon has been previously reported for quail (Ottinger and Gorham, 1986) and broiler breeder males (Wolanski et al., 2004a). The level of testicular regression observed in males at 61 wk was roughly 10 % in both barns, however males which had either died or were culled out had a 40 % incidence of testicular regression. This may suggest that males which died or were culled out were not receiving adequate nutrients to maintain testicular function or prolonged stressful events resulted in a cessation of semen production.

4.3.5 Foot Pad and Feather Score

In terms of foot pad condition, the males in Barn 2 had significantly better foot pad condition when compared to males in Barn 1 (Table 4-3). In a broiler trial by Bilgili et al. (2006), a visual ranking system for foot pad condition was developed and these authors found that >50 % of female broilers had mild foot pad lesions (lesion ≤7.5 mm in size). Currently, broilers go to market between 37 to 52 days of age depending on market requirements, however broiler breeders have a life span of 58 to 63 wk. Therefore foot pad condition of broiler breeders needs to be evaluated to ensure that foot pad condition does not negatively influence breeding, feeding, or BW of broiler breeder stocks. In a review by Mayne (2005), it was reported that poor litter conditions such as wet or caked litter were linked with the development of foot pad lesions in both turkeys and broilers. Wolanski et al. (2004a) has reported that older males (63 wk) had poorer foot pad condition (1.92 mean score) than younger spiked males (48 wk) (2.13 foot score) at the end of a production cycle.

Feather score was not affected by barn or BW category. The majority of the males assessed at 61 wk received a feather score of 5, which was equated to perfect feather cover. The lowest feather score was given to LOW BW birds in Barn 1 (4.63) which still equates to adequate feather coverage.

4.3.6 Mortality and Culling

The rate of mortality in this study was reported every 9 wk from hatch until depopulation with the underlying cause of death varying over time (Figure 4-2). Post photo-stimulation (27, 36, 45, 54, 61 wk) the proportion of male deaths which were attributed to aggression/infection increased at a dramatic rate being 6.5, 14.3, 17.3, 19.6,

and 20.8 % respectively. Male mortality continues to be a problem in the broiler breeder industry, an initial report by Peak and Brake, (2000) had male mortality rates of 49 %. In research by Parker and McDaniel (2002), males were integrated with hens at a level of 9 males per 100 hens at 26 wk, however by 51 wk male mortality had reduced male numbers to 5.5 %. Increased research into male aggression and immune status of males may be warranted as these rates of mortality are significant when compared to the culling rate of only 5.9 % for the entire 61 wk period in this study.

Total mortality by 61wk was 38.6% with the majority (26.1 %) of all mortality occurring during the 27 wk to 45 wk period. In contrast, the level of mortality during the entire rearing period (0-18 wk) was extremely low at 2.8 % (Figure 4-2). By 27 wk of age mortality in the males increased to represent nearly 14 % of all males which were surveyed in this study. The males were photo-stimulated at 23 wk of age with sexual maturation following after approximately 2 to 3 wk. The level of circulating testosterone would have increased following sexual maturation as the testes become functional.

It was interesting to note that these males were reared on a concave growth profiles as suggested by Peak and Brake, (2000) and the mortality observed in this study (38.6 %) matches the values of flocks raised on similar concave feeding programs. Feed restriction and management practices have reduced the level of mortality in broilers (Robinson et al., 1992; Fontana et al., 1992; Arce et al., 1992). For breeder males a management practice such as this might be developed to reduce the current level of male mortality being experienced in the industry. This would serve to increase fertility of flocks, improve animal welfare, and reduce the number of males raised and thus increasing producer profits.

4.3.7 Correlations

Correlations between hatch data and rearing measurements are reported in Table 4-4. There were no strong correlations between hatch traits and juvenile BW or length measures. However, by 4 wk of age male BW correlated with 18 wk weight ($r = 0.46$) and the strength of correlation nearly doubled when 8 wk weight was correlated ($r = 0.75$) to 18 wk BW. Therefore it was suggested that less emphasis should be placed on hatch weight as the correlation to 18 wk weight was low ($r = 0.14$);($p = 0.027$). The relationship between hatch weight and mature BW has been demonstrated to be extremely low (Chapter 2). In work with broilers which had *ad-libitum* access to feed, frame size correlated more strongly to future BW than did hatch weight (Wolanski et al., 2004b). However under conditions of feed restriction, which results in intense competition between males for a limited amount of feed, male drive or circulating testosterone level may have a more profound effect when compared to bird size.

Table 4-5 describes the correlations and interrelationships between juvenile BW (18 wk) and 61 wk traits. There was a low correlation between 18 wk weight and 61 wk weight ($r = 0.17$) suggesting that competition along with other factors in a breeder barn significantly influence male BW over a breeding cycle. There were significant correlations between 61 wk weight and both breast muscle weight ($r = 0.89$) and keel length ($r = 0.63$). Testes weight also moderately correlated with mature BW ($r = 0.44$) which agrees with a previous report by Wolanski et al. (2004a).

4.3.8 Conclusions and Applications

Mortality during rearing (0 – 18 wk) was extremely low (2.8 %), however mortality increased dramatically after sexual maturity and by flock dispersal mortality

accounted for 38.6 % of all males placed. BW at 18 wk did not correlate well with 61 wk weight (r = 0.16546) therefore numerous factors beside juvenile BW influence mature BW. Males which died or were culled out had a 40 % incidence of regressed testes (<15 g) whereas males that survived until depopulation had a 10 % incidence of testicular regression.

4.4 REFERENCES

Arce, J., M. Berger, and C. Lopez-Coello. 1992. Control of ascites syndrome by feeding restriction techniques. J. Appl. Poult. Res. 1:1-5.

Bilgili, S. F., M. A. Alley, J. B. Hess, and M. Nagaraj. 2006. Influence of age and sex on footpad quality and yield in broiler chickens reared in low and high density diets. J. Appl. Poult. Res. 15:433-441.

Brillard, J. P., and G. R. McDaniel. 1986. Influence of spermatozoa numbers and insemination frequency on fertility in dwarf broiler breeder hens. Poult. Sci. 65:2330-2334.

Deakin, D. E., C. Boulton, and C. G. Moran. 2007. Mortality and causes of death among patients with isolated limb and pelvic fractures. Injury-Int. J. Care of the Injured. 38:312-317.

Fontana, E. A., W. D. Weaver, Jr., B. A. Watkins, and D. M. Denbow. 1992. Effect of early feed restriction on growth, feed conversion, and mortality in broiler chickens. Poult. Sci. 71:1296-1305.

Fox, C. W., L. Dublin, and S. J. Pollitt. 2003. Gender differences in lifespan and mortality rates in two seed beetle species. Functional Ecology. 17:619-626.

Ingram, D. R., and L. F. Hatten, III, B. N. McPherson. 2001. Effects of initiation age of skip-a-day feed restriction on skeletal development in broiler breeder males. J. Appl. Poult. Res. 10:16-20.

Marks, H. L. 1995. Genetics of Growth and Development. Pages 170-182 in World Animal Science, Poultry Production. P. Hunton, ed. Elsevier, Amsterdam.

Mayne, R. K. 2005. A review of the aetiology and possible causative factors of foot pad dermatitis in growing turkeys and broilers. World's Poult. Sci. J. 61:256-267.

Moran, E. T., Jr. 1995. Body Composition. Pages 143-148 in World Animal Science, Poultry Production. P. Hunton, ed. Elsevier, Amsterdam.

McCartney, M. G., and H. B. Brown. 1980. Effects of feed restriction on reproductive performance of broiler breeder males. Poult. Sci. 59:2583-2585.

McGary, S., I. Estevez, and M. R. Bakst. 2003. Potential relationships between physical traits and male broiler breeder fertility. Poult. Sci. 82:328-337.

Ottinger, M. A., and S. L. Gorham. 1986. Histological and neuroendocrine correlates of the age-related reproductive decline in male quail. Poult. Sci. 65 (Suppl. 1):100. (Abstr.).

Parker, H. M., C. D. McDaniel. 2002. Selection of young broiler breeders for semen quality improves hatchability in an industry field trial. J. Appl. Poult. Res. 11:250-259.

Peak, S. D., and J. Brake. 2000. The influence of feeding program on broiler breeder male mortality. Poult. Sci. 79 (Supp l):2. (Abstr.).

Peebles, E. D., S. M. Doyle, T. Pansky, P. D. Gerard, M. A. Latour, C. R. Boyle, and T. W. Smith. 1999. Effects of breeder age and dietary fat on subsequent broiler performance. 1. Growth, mortality, and feed conversion. Poult. Sci. 78:505-511.

Renema, R. A., F. E. Robinson, R. M. Beliveau, H. C. Davis, and E. A. Lindquist. 2007. Relationships of body weight, feathering, and foot pad condition with reproductive and carcass morphology of end-of-season commercial broiler breeder hens. J. Appl Poult. Res. 16:27-38.

Robinson, F. E., H. L. Classen, J. A. Hanson, and D. K. Onderka. 1992. Growth performance, feed efficiency and the incidence of skeletal and metabolic diseases in full-fed and feed restricted broiler and roaster chickens. J. Appl. Poult. Res. 1:33-41.

Saleh, E. A, S. E. Watkins, A. L. Waldroup, and P. W. Waldroup. 2005. Effects of early quantitative feed restriction on live performance and carcass composition of male broilers grown for further processing. J. Appl. Poult. Res. 14:87-93.

Sinclair, R. S., F. E. Robinson, and R. T. Hardin. 1990. The effects of parent age and posthatch treatment on broiler performance. Poult. Sci. 69:526-534.

Speer, B. L. 1996. Developmental Problems in Young Ratites. Pages 148-149 in Ratite Management, Medicine, and Surgery. T. N. Tully and S. M. Shane, ed Krieger, Malaber, FL.

Wolanski, N. J., R. A. Renema, F. E. Robinson, and J. L. Wilson. 2004a. End-of-season carcass and reproductive traits in original and replacement male broiler breeders. J. Appl. Poult. Res. 13:451-460.

Wolanski, N. J., E. J. Luiten, R. Meijerhof, A. L. J. Vereijken. 2004b. Yolk utilization and chick length as parameters for embryo development. Avian and Poult. Biol. Rev. 15:233-234.

Wolanski, N. J., R. A. Renema, F.E. Robinson, V. L. Carney, and B. I. Fancher. 2006. Relationship between chick conformation and quality measures with early growth traits in males of eight selected pure or commercial broiler breeder strains. Poult. Sci. 85:1490-1497.

Wolanski, N. J., R. A. Renema, F.E. Robinson, V. L. Carney, and B. I. Fancher. 2007. Relationship among egg characteristics, chick measurements, and early growth traits in ten broiler breeder strains. Poult. Sci. 86:In press.

Wyatt, C. L., W. D. Weaver, Jr., and W. L. Beane. 1985. Influence of egg size, eggshell quality and posthatch holding tie on broiler performance. Poult. Sci. 64:2049-2055.

TABLE 4-1. Descriptive data which shows BW, length measures, and variability of traits from hatch to 18 wk of age for broiler breeder males as compared to the Ross management guide

Parameter	n	Observed	Ross male guide[1]	CV
Hatch BW (g)	530	42.7		7.91
Hatch body length (mm)[2]	530	181.0		2.81
Hatch shank length (mm)[3]	530	29.6		3.81
4 wk BW (g)	515	534.6	690	18.3
8 wk BW (g)	493	1351.7	1400	15.0
8 wk shank length (mm)[3]	493	100.8		4.77
8 wk keel length (mm)[4]	493	120.4		5.39
12 wk BW (g)	496	1750.8	1920	15.3
16 wk BW (g)	499	2206.5	2420	15.4
16 wk shank length (mm)[3]	499	126.0		4.45
16 wk keel length (mm)[4]	499	153.3		5.27
18 wk BW (g)	494	2545.0	2710	15.2

[1] Ross Management Guide 2006, Aviagen North America, Huntsville Alabama.
[2] Measured from tip of the bird's beak to the end of the middle toe (not including the nail).
[3] Measured from the top of the hock joint to the bottom of the foot pad.
[4] Measured from the hypocleido-clavical joint to the caudal end of the sternum.

TABLE 4-2. Body weight, carcass morphometrics and liveability of males sorted by barn and BW category (at 18 wk) at the time of depopulation (61 wk)

Source	18 wk		61 wk				
	n	BW (g)	n	BW (g)	Shank length (mm)	Keel length (mm)	Mortality (%)
Barn							
#1	207	2679	142	4999	142.9[a]	192.9	33.0[b]
#2	222	2709	114	4812	140.6[b]	190.1	51.1[a]
SEM		15.6		81.9	0.7	1.2	0.03
Barn 1 BW Category[1]							
LOW	58	2179[c]	40	4826[b]	140.4[b]	189.9[b]	36.5
STD	90	2681[b]	64	4870[b]	142.0[b]	190.6[b]	28.9
HIGH	59	3176[a]	38	5301[a]	146.4[a]	198.2[a]	35.6
SEM		34.5		142	1.3	2.1	0.06
Barn 2 BW Category[1]							
LOW	67	2178[c]	29	4682	141.5	188.5	62.8
STD	95	2655[b]	49	4825	139.9	189.7	48.4
HIGH	60	3294[a]	36	4930	140.3	192.2	40.0
SEM		38.7		211	1.9	3.1	0.06
Source of variation							
Barn		0.1625		0.699	0.0104	0.0707	0.0005
BW Category		0.0001		0.0433	0.1491	0.0178	0.0828
Barn X BW Category		0.0475		0.4810	0.0108	0.4723	0.2068

[a-c] Means within a column with different superscripts differ significantly ($P<0.05$).

[1] Birds were sorted based on 18 wk BW; STD birds were within half a standard deviation above and below the mean; LOW birds were greater that half a standard deviation below the mean; and HIGH birds were greater than half a standard deviation above the mean.

TABLE 4-3. Dissection results and bird feather and foot scores of male broiler breeders at 61 wk of age

Source	n	Breast wt		Left testis wt (g)	Right testis wt (g)	Total testes wt (g)	Foot score[2]	Feather score[3]
		(g)	%					
Barn								
#1	142	749.6	15.1	13.4[a]	12.8[a]	26.3[a]	2.12[b]	4.72
#2	114	718.9	14.9	11.6[b]	10.8[b]	22.4[b]	2.42[a]	4.82
SEM		15.9	0.2	0.6	1.0	0.9	0.07	0.05
Barn 1BW Category[1]								
LOW	40	744.5	15.3	13.5	12.6	26.1	2.03	4.63
STD	64	728.2	14.9	14.1	13.2	27.3	2.30	4.77
HIGH	38	776.0	15.1	12.6	12.8	25.4	2.05	4.76
SEM		26.8	0.3	1.1	1.0	1.5	0.12	0.08
Barn 2BW Category[1]								
LOW	29	684.5	14.8	11.8	11.2	23.0	2.28	4.72
STD	49	740.6	15.0	12.5	11.6	24.1	2.41	4.84
HIGH	36	731.6	14.9	10.5	9.5	20.1	2.58	4.89
SEM		30.7	0.3	1.7	1.5	1.8	0.13	0.09
Source of variation								
Barn		0.1414	0.4580	0.0262	0.0059	0.0116	0.0013	0.1250
BW Category		0.3726	0.9299	0.2416	0.4154	0.3046	0.1711	0.1493
Barn X BW Category		0.2987	0.4655	0.9872	0.6533	0.8694	0.1464	0.9343

[a-c] Means within a column with different superscripts differ significantly ($P<0.05$).

[1] Birds were sorted based on 18 wk BW;STD were within half a standard deviation above and below the mean; LOW birds were greater that half a standard deviation below the mean; and HIGH birds were greater than half a standard deviation above the mean.

[2] Evaluated on a scale of 1 to 3: where 1 = poor condition characterized by large, open sores or severe lesions; 2 = average condition characterized by few open sores or swollen lesions; 3 = excellent footpad condition characterized by little to no open sores or swollen lesions.

[3] Feather coverage evaluated on a 1 to 5 as follows: 1 = completely bare back; 2 = bare back with some tail feathers present; 3 = bare patches across midsection of bird; 4 = small bare patch in center of birds back; 5 = complete feather coverage.

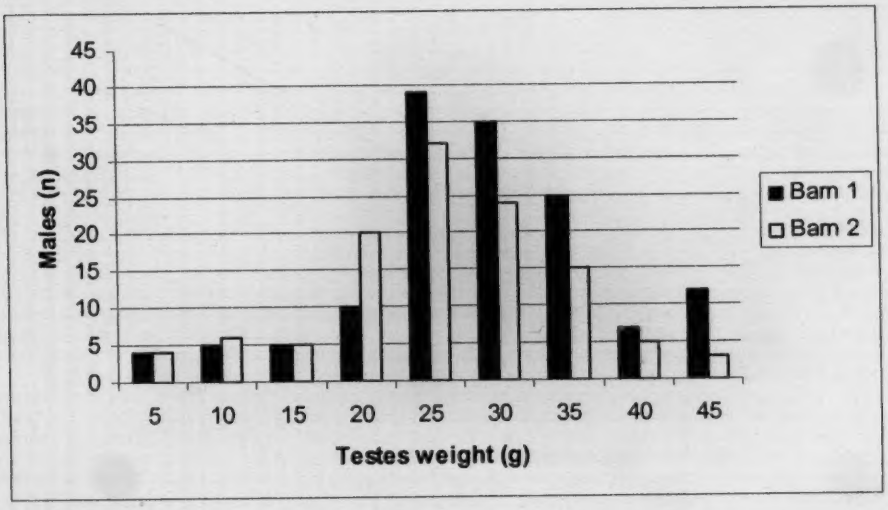

FIGURE 4-1. Frequency of distribution for testes weight of males sorted by barn at 61 wk (n = 142 for Barn 1 and 114 for Barn 2).

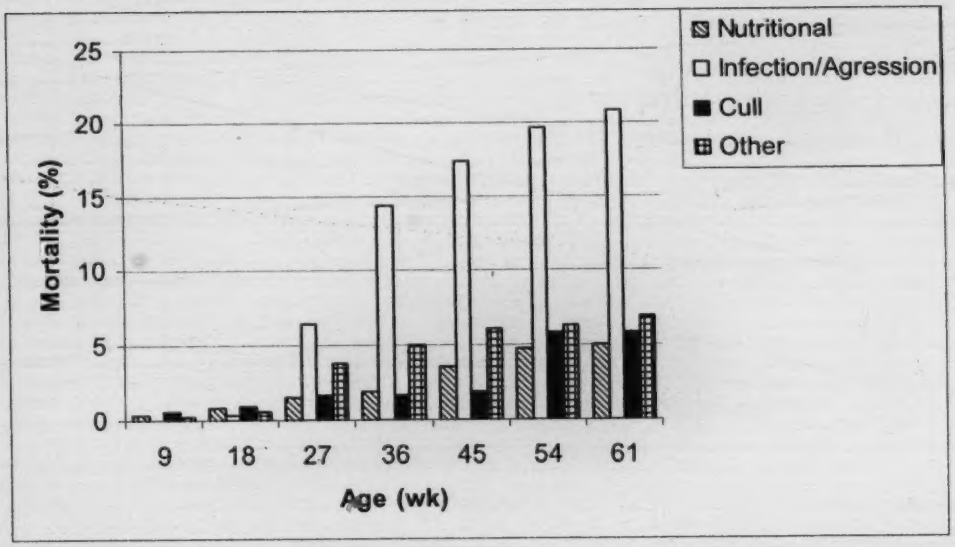

Figure 4-2. Cumulative mortality of males from hatch to 61 wk with the cause of death as determined by post-mortem examination.

TABLE 4-4. Correlation coefficients (and P-values) of hatch traits and early growth measurements in juvenile male broiler breeders

Variable	Hatch body length	Hatch shank length	4 wk BW	8 wk BW	8 wk keel length	8 wk shank length	12 wk BW	16 wk BW	16 wk keel length	16 wk shank length	18 wk BW
Hatch weight	0.21544 (0.0001)	0.27006 (0.0001)	0.13194 (0.0027)	0.12617 (0.0050)	0.08571 (0.0572)	0.12829 (0.0043)	0.15641 (0.0005)	0.12203 (0.0071)	0.12029 (0.0071)	0.12543 (0.0051)	0.14294 (0.0265)
Hatch body length		0.37398 (0.0001)	0.00758 (0.8637)	0.04390 (0.3307)	0.10147 (0.0243)	0.14474 (0.0013)	0.10220 (0.0228)	0.09929 (0.0266)	0.15839 (0.0004)	0.17052 (0.0001)	0.12949 (0.0039)
Hatch shank length			0.01084 (0.8061)	0.04850 (0.2825)	0.09791 (0.0297)	0.14567 (0.0012)	0.10326 (0.0214)	0.08807 (0.0493)	0.12208 (0.0063)	0.20100 (0.0001)	0.10500 (0.0196)
4 wk BW				0.78001 (0.001)	0.66370 (0.0001)	0.62194 (0.0001)	0.61957 (0.0001)	0.51822 (0.0001)	0.45706 (0.0001)	0.40738 (0.0001)	0.46492 (0.0001)
8 wk BW					0.72722 (0.0001)	0.75154 (0.0001)	0.84688 (0.0001)	0.77896 (0.0001)	0.68191 (0.0001)	0.64661 (0.0001)	0.74933 (0.0001)
8 wk keel length						0.62687 (0.0001)	0.62707 (0.0001)	0.55089 (0.0001)	0.72805 (0.0001)	0.54976 (0.0001)	0.53948 (0.0001)
8 wk shank length							0.67423 (0.0001)	0.60555 (0.0001)	0.58318 (0.0001)	0.76250 (0.0001)	0.57650 (0.0001)
12 wk BW								0.90190 (0.0001)	0.74786 (0.0001)	0.71310 (0.0001)	0.87443 (0.0001)
16 wk BW									0.75061 (0.0001)	0.73486 (0.0001)	0.93664 (0.0001)
16 wk keel length										0.66481 (0.0001)	0.76546 (0.0001)
16 wk shank length											0.73462 (0.0001)

TABLE 4-5. Correlation coefficients (and P-values) of 18 wk weight and 61 week traits in male broiler breeders

Variable	61 wk BW	Shank length	Keel length	Breast muscle weight	Testes weight
18 wk BW	0.16546 (0.0089)	0.19050 (0.0025)	0.18035 (0.0043)	0.12542 (0.0485)	0.00384 (0.9520)
61 wk BW		0.39789 (0.0001)	0.62951 (0.0001)	0.89409 (0.0001)	0.43616 (0.0001)
Shank length			0.40755 (0.0001)	0.35054 (0.0001)	0.21926 (0.0004)
Keel length				0.59344 (0.0001)	0.16410 (0.0085)
Breast muscle weight					0.27861 (0.0001)

5.0 INDIVIDUAL FEMALE BROILER BREEDER GROWTH, VARIABILITY, AND REPRODUCTIVE PERFORMANCE FROM HATCH TO FLOCK DISPERSAL IN A COMMERCIAL SETTING

5.1 INTRODUCTION

Broiler breeders are intensively feed restricted during the pullet growth phase to limit early growth, prevent excessive fatness, and ensure future egg production. Feed restriction of broiler breeders has resulted in improved egg production (Wilson et al., 1989), increased hatchability, and reduced mortality of hens (Katanbaf et al., 1989; Renema and Robinson, 2004). In a commercial setting, the implementation of feed restriction programs can be difficult. Current breeder parent stocks have been selected for increased BW and meat yield which has implications on reproductive function of hens. A study by Hocking and Robertson (2000), compared selected and relaxed lines (no selection for 20 years) and found that selected lines had higher BW, with more large yellow follicles (LYF), and a higher incidence of follicular atresia. Feed restriction during the period from 7 to 15 wk of age has been found to be most beneficial for ensuring adequate egg production of broiler breeder pullets later in life (Bruggeman et al., 1999). Breeder hens which are overfed will recruit excess LYF (10 to 14 follicles) as compared to restricted hens which begin lay with 6 to 8 (Hocking et al., 1987). Extra follicles tend to cause reproductive problems such as internal ovulations, defective eggs, or double yolked eggs. It has been well documented that extra feed accelerates the onset of sexual maturity in breeder hens (Bartov and Wax, 1998; Renema et al., 1999). Therefore, breeding companies have developed management guides which assist producers in making feeding, lighting, and other management decisions for newly developed breeding stock.

Breeding companies have advocated that flock uniformity can be a measurable trait that producers can use to gauge bird growth. Uniformity can be expressed numerous ways but the Ross management guide (Anonymous, 2003) recommends using Coefficient of Variation (CV) method because this method provides an accurate determination of what percentage of a flock needs attention (ie low CV's are desirable). Producers strive for flocks with a high degree of uniformity in bird weight because, larger birds may exert an influence over smaller counterparts if feed has not been distributed evenly or quickly resulting in poor flock uniformity (North, 1980). In the broiler breeder industry, use of sex separate rearing and sex separate feeding has been implemented to achieve slightly different BW profiles for the two sexes.

In the pullet-phase, breeder females are laying down the foundation for future egg production. Frame size can be largely determined prior to sexual maturity in domestic fowl. Research by Hudson et al. (1993), showed that in Leghorn stocks, bone growth stops at sexual maturity and generally, future bone growth only occurs once hens stop laying. More recently Hudson et al. (1999), found that broiler breeder hens were very similar to Leghorns in terms of bone growth. Hudson et al. (1999), stressed the importance of maximizing bone development in breeders as well as layers prior to sexual maturity because this calcium source would be utilized during the egg production cycle of both birds. Research has shown that frame size of breeders can be altered by selection programs and the nutritional status of the birds. Reddish and Lilburn, (2004) compared two high breast-yielding strains of breeder pullets to a comparable strain with less emphasis on breast yield and found differences in tibia and femur length and width among the strains. Dunnington and Siegel, (1996) documented that selection can impact

how feed resources are allocated within the bird. In breeders, a negative regression between BW at 22 wk and the age at first egg has been reported (Bartov et al., 1994), therefore heavier birds would have a shorter time to first egg. Bartov and Wax (1998), reported that high BW at 18 wk resulted in a higher proportion of hens dropping out of egg production before the termination of the experiment (60 wk). The objective of this experiment was to investigate the relationship between the juvenile growth profile of a pullet to future egg production and ability to sustain lay.

5.2 MATERIALS AND METHODS

5.2.1 Stocks and Management

This study examined, two consecutive Ross 308 flocks (Aviagen North America, Huntsville, AL) at a single hatching egg facility. The flocks had similar numbers of females placed (Flock #1 had 4078 females and Flock #2 had 4289). At hatch, 725 female chicks in each of these two flocks were neck tagged and weighed. The bird morphometrics were characterized by measuring the shank length (from the tibia and femur junction to the base of the foot pad) and total bird length (from the beak to the tip of toe not including nail). The navel condition and abdomen score were evaluated for each bird. Navel imperfections such as navel wick (membrane attached to navel) or navel button (slight opening of navel) were recorded. The abdomen was palpated by a single trained individual in an effort to estimate residual yolk mass as per the abdomen scale reported in Chapters 2 and 3.

Flock 2 experienced a coccidiosis challenge which was treated with Amprol at 3 wk. At 9 wk of age birds which had been tagged at hatch were sorted out of the entire flock and weighed and wing banded. The length of the shank and keel of pullets were

measured using digital callipers to the nearest 0.1 mm. Just prior to housing (19 wk) the BW, shank length, and keel length were recorded on the tagged birds.

The PS program reared pullets on 8 L and 16 D until 22 wk and light was increased by 4 h each wk until a maximum day length of 16 h was reached. Flock 1 was PS at 22 wk and PS in Flock 2 was delayed until 23 wk to allow pullets to achieve appropriate BW and fleshing. During lay, egg production records were kept for each barn to compare egg production between the two flocks and the breeder guideline. Flock 2 was accidentally fed a pullet ration at 33 wk of age, which may have negatively influenced egg production as this feed did not have sufficient calcium for eggshell formation. After detection of the feed delivery error, birds were fed standard breeder rations for the remainder of the trial.

5.2.2 61 wk Data Collection

At the time of flock dispersal (61 wk), tagged birds were sorted out of the entire breeder flocks and penned. A single trained individual attempted to evert each hen's oviduct by using methods adopted from routine artificial insemination of breeder stock hens. Hens which had a visible oviduct were predicted as in lay and hens which failed to evert their oviduct were classified as out of lay (Figure 5-1). Hens were killed by cervical dislocation, and feather cover, shank length, keel length, and BW were recorded. Shank and keel measurements have been previously described by Joseph et al. (2002). The feather score has been previously described by Renema et al. (2007). In brief, a score of 1 equated to a female with poor feather cover and large areas where the naked back was visible. A score of 5 indicated a female that had complete feather coverage with no signs of feather wear or loss.

Hens were dissected to characterize total ovary weight, number of LYF (>10 mm in diameter), and fat pad weight. The incidence of reproductive disorders such as internal ovulation, internal lay, and follicular atresia was recorded. By using the oviduct eversion test on the hens and then relating this data to dissection results of the ovary, it may provide hatching egg producers with a tool which can assist in making difficult culling decisions.

5.2.3 Statistical Analysis

Data collected prior to 61 wk were analyzed as a one way Anova with flock as the main effect. Birds at 61 wk were sorted into 3 BW categories equally distributed around the mean BW (low; LOW = birds with <3750 g; standard; STD = birds with 3750 to 4180 g; and high; HIGH = birds with > 4180 g). Data were analyzed with flock and BW category as main effects for all 61 wk data. All data were analyzed using SAS systems 2003 with the Proc Mixed procedure. Level of significance was assessed at $P \leq 0.05$. The descriptive data were compared using a chi-square analysis.

5.3 RESULTS AND DISCUSSION

5.3.1 Rearing Data

The length measurements and hatch weights for both flocks are presented in Table 5-1. Flock 2 was significantly heavier than Flock 1 at hatch with mean weights of 39.7 and 38.4 g respectively. The same trend was found for hatch length and shank length measures with Flock 2 being significantly longer than Flock 1 (Table 5-1). Although Flock 2 was 1 g heavier at hatch this flock experienced coccidiosis prior to 9 wk of age, therefore BW of Flock 2 was significantly lower at 9 and 19 wk. This disease challenge also negatively impacted the frame size of the pullets in Flock 2. In respect to shank

length, Flock 2 had a 5 and 7 mm disadvantage at 9 and 19 wk of age (Table 5-1). The difference in keel length between the two flocks at 19 wk was more profound with Flock 1 having a 153.5 mm keel compared to Flock 2 which had a keel length of 140.9 mm.

Frame size of breeders has been shown to impact the early egg size. The measurement of long bones such as the shank or keel bone in poultry has been an accepted means for assessing skeletal development of live birds (Lerner, 1937; Leeson and Summers, 1984; Ingram et al., 2001). In broiler breeder males, the shank length was shown to be less influenced by feed restriction than a bird's keel length or head width (Ingram et al., 2001). During the early rearing period, a pullet's frame size rapidly develops and extended feed shortage or disease status can impact ultimate mature frame size. Feed restriction of broiler breeder females has been shown to decrease shank length (Yu et al., 1992; Fatori et al., 1993). Hudson et al. (2000) has shown that restricting the CP intake of female broiler breeder pullets results in a reduction of both shank length and keel length.

At 9 wk, pullets in Flock 2 had a higher coefficient of variation (CV) (14.6 %) as compared to Flock 1 which had a CV of (13.9 %). This result likely reflects the fact that some birds in Flock 2 lost BW due to the coccidiosis challenge whereas other birds were unaffected. At 19 wk, Flock 1 was 200 g above target BW and Flock 2 was 200 g below target BW, however by 61 wk BW was the same at 3.9 kg for each flock. The degree of uniformity at 19 wk in Flocks 1 and 2 may have been influenced by the coccidosis challenge experienced in Flock 2 as CV values were 13.8 % (Flock 2) and 11.0 % (Flock 1). Our data were in agreement with that of Robinson and Robinson, (1991), which showed that although BW prior to PS was significantly lower for some birds, by the end

of lay (61 wk) the BW were not different. Hudson et al. (2001) found that uniformity of BW in breeder hens generally improved as the birds aged. When birds were sorted into a highly uniform group (98 % within ±15 % of the mean) at 20 wk, the uniformity remained over 90 % by 35 wk (Hudson et al.,2001). In general highly uniform flocks will reach peak lay sooner and have a higher peak production than flocks with poor uniformity (North, 1980). Therefore, prior to the transfer of pullets from the rearing to the lay barn achieving a high degree of uniformity may have economic benefits.

5.3.2 Egg Production

Egg production records were kept for both flocks and these were compared to the production targets for the Ross 308 guide (Table 5-2). Due to a delay in the age of photo-stimulation, Flock 2 reached 5 % production later than Flock 1 (25.5 wk and 24.5 wk respectively). Also, the age at peak production was shifted later for Flock 2, which reached peak lay at 32 wk as compared to Flock 1 which peaked at 31 wk. In terms of peak lay, Flock 1 peaked at 83.4% while Flock 2 reached a peak lay of 79.6 %. Although peak lay can be a valuable tool to gauge egg production in a flock this measure only takes into account a single point in time. On the other hand, a graph of persistency displays the laying patterns for the life of a flock. Flock 1 had an advantage in egg production for the majority of lay (25 wk – 51 wk) which may be partially explained by the coccidiosis experienced or the accidental feeding of pullet feed at 33 wk in Flock 2. It was apparent that post-peak-lay Flock 2 had better persistency for the final 5 wk of production (Figure 5-2). Table 5-2 reports the egg production at 61 wk along with the total number of eggs per hen housed and total mortality. Flock 2 had better egg production at 61 wk when compared to Flock 1 (53.9 % and 48.3 % respectively). Research by Hudson et al. (2001)

suggested that heavy hens tend to commence lay before light hens, therefore toward the end of a flock these heavy hens might also cease egg production sooner.

Modest delays in sexual maturity in broiler breeders hens do not adversely effect total egg production or egg numbers (Yuan et al., 1994; Robinson et al., 1996) and, this practice has been proven to increase early egg size (Joseph et al., 2002). In broiler breeders, egg production typically increases rapidly for 11- 12 wk following photo-stimulation until birds reach peak egg production then following peak lay a steady decline in egg production occurs until depopulation (Grossman et al., 2000). In flocks which are below target weight, delaying photo-stimulation has been shown to allow underweight pullets to achieve a more mature frame size as measured by shank and keel lengths (Robinson et al., 1996). In a study by Sun and Coon (2005), heavy BW pullets produced an additional 3 eggs prior to peak lay due to an earlier commencement of lay, and heavier pullets were noted to reach 50 % production 4 to 5 d earlier. Interestingly, the egg production between the bodyweight groups was similar by 65 wk of age. BW has been shown to be a key determinant of when birds begin lay (Robinson et al., 1993; Lopez and Leeson, 1994). Work by Robinson et al. (1995), found that hens which were slightly heavier (105 % of breeder recommended BW) at 20 wk had the best early lay performance when compared to target and underweight hens. Leeson and Summers, (1987) also noted an advantage of increased BW on egg production during the first 28 d of lay, however, the effects were not evident after this time. Body weight has been shown to significantly affect egg weight with larger hens producing significantly larger eggs at all stages of lay (pre-peak, peak, and post-peak) (Sun and Coon, 2005).

5.3.3 Mortality

Hen mortality in the US breeder industry has been reported to range from 17- 22 % (Agri Stats 2002; Hudson et al., 2004). In the Aviagen management guide, the reported mortality was lower at 14.5 % to 65 wk of age (Anonymous, 2003). In the current study hen mortality in the two flocks were 12.8 % and 9.9 % for Flock 1 and Flock 2, respectively.

5.3.4 61 wk External Morphometrics and Dissection

In Table 5-3 the BW, shank length, keel length and reproductive condition are reported by flock and BW category for each flock at 61 wk. Of the 725 chicks tagged at hatch, by 61 wk only 497 (Flock 1) and 564 (Flock 2) were found after sorting through the entire flocks Although these two flocks were almost 400 g different in BW at 19 wk, the 61 wk weight was not significantly different. At flock dispersal, Flock 1 weighed 3.97 kg and Flock 2 weighed 3.95 kg. The compensatory growth in Flock 2 was likely due to the fact that photo-stimulation was delayed until 23 wk in this flock, to allow the pullets to reach an appropriate BW and fleshing.

In terms of length measures, the shank and keel length remained significantly greater in Flock 1 than in Flock 2. However, the magnitude of difference decreased with Flock 1 having a 1 mm advantage in shank length and a 5 mm advantage in keel length (Table 5-3).

In terms of reproductive condition, Flock 2 was in better condition at 61wk of age compared to Flock 1 (Table 5-3). Flock 2 hens had an average ovary weight that was 67.3 vs 60.5 g in Flock 1. Joseph et al. (2002) reported that ovary weight of 53 wk hens was increased in birds which were photo-stimulated at 23 wk as compared to hens light at

20 wk. Flock 2 had nearly 1 extra follicle compared to Flock 1 at 61 wk of age. When birds were sorted by the number of LYF remaining at the end of lay, Flock 1 had a greater proportion of hens that had ceased egg production or had fewer LYF (Figure 5-3). In Flock 1, nearly 10 % of hens had no LYF while in Flock 2 only 5 % had no LYF. Joseph et al. (2002) also reported that delayed lighting of pullets resulted in a greater number of LYF at the time of depopulation. Robinson et al. (1990) has demonstrated that as breeder hens age the sequence length decreases resulting in a greater number of pause days toward the time of flock dispersal (62 wk). Therefore the fact that Flock 2 had a heavier ovary and a greater number of LYF at the time of flock dispersal may have been affected by the delayed photostimulation of this flock or the rate of lay (Figure 5-2). There was no flock effect on fat pad weight on an absolute or percentage basis.

5.3.5 Birds Sorted by BW

Table 5-3 also shows that BW category significantly influenced all traits examined at 61 wk. HIGH birds consistently had the highest BW, fat pad weight, shank length, and keel length with STD birds being significantly different than either the HIGH or LOW. These findings were in agreement with research by Renema et al. (2007) where BW category was shown to significantly impact skeletal size parameters. In terms of ovary weight, LOW birds in both Flock 1 (50.0 g) and Flock 2 (60.4) were significantly lighter in LOW birds as compared to STD or HIGH birds. In Flock 2, birds in all BW categories had ovary weights which were significantly different from each other (LOW 60.4 g; STD 69.0 g; and HIGH 72.5 g). The number of LYF for the two LOW groups was lower than the number observed in the higher BW categories. For example in Flock 1, LOW weight hens had 4.0 LYF while STD and HIGH weight hens had 5.1 and 5.0

LYF respectively. This information suggests that a higher percentage of LOW BW hens had ceased lay by 61 wk.

5.3.6 Reproductive Condition

At flock dispersal, the incidence of reproductive disorders such as internal ovulation, internal lay, atretic follicles were also characterized (Table 5-4). In Flock 2, nearly 14 % of hens had one or more of the above reproductive disorders while only 9.9 % of hens in Flock 1 had a reproductive disorder. Flock 1 had 9.8 % of birds out of lay and Flock 2 had 4.6 % of hens out of lay. The actual number of birds out of lay corresponded well with the oviduct eversion test which allowed the prediction of lay status of hens. This test predicted that 43 and 21 birds were out of lay at 61 wk; and the actual numbers of birds with no LYF was 48 and 26 for Flock 1 and Flock 2 respectively. Previous research has shown that feather coverage was unable to predict lay status in hens (Renema et al., 2007).

The effects of BW category showed that a higher proportion of LOW weight hens had gone out of lay. In Flock 1, the oviduct eversion test predicted that 35 hens were out of lay and upon dissection it was confirmed that 33 LOW weight hens (23.7 %) had no LYF. In comparison the STD and HIGH BW categories had 3.0 and 5.8 % of hens out of lay in Flock 1. Although it has been documented that overweight hens are more prone to reproductive disorders, our results did not indicate this.

Determination of the reproductive status of a hen can be difficult because the ovary and oviduct are located within the body cavity. One unique method developed for monitoring the onset of sexual maturity in Japanese Quail used measuring sticks to evaluate the spread of the pubic bones (Satterlee and Marin, 2004), thus allowing the

prediction of when lay will commence. In turkeys, artificial insemination has been used exclusively due to intensive genetic selection for breast muscling which has limited the reproductive capabilities of broad breasted stocks. During artificial insemination, the hen's oviduct must be exteriorized outside her body by applying slight pressure to the hen's abdomen while at the same time pushing down on the vent area. Hens which fail to evert are said to be tight and have likely dropped out of egg production. In this trial an oviduct eversion test was designed which enabled the prediction of whether a hen was actively in lay or had ceased egg production based on a visual observation of the vent area (Figure 5-1). Gill and Amann, (2002) stated that the poultry industry lacked a practical approach to detect and cull out sub-fertile hens therefore, it was hoped that this oviduct eversion test would allow producers to make better culling decisions. The visual observation of the hen's oviduct was effective in identifying non-laying birds 75 % of the time. Traditional phenotypic indicators which have been used to make culling decisions such as poor feathering or low BW can be misleading, resulting in incorrect culling decisions. Since feed costs represent a large proportion of production costs for hatching egg producers, the identification of individual birds which were out of lay and simply consuming feed could be of economic interest. Overweight hens represent an economic cost to the produces as these birds usually are over consuming feed and produce eggs which are unfit for hatching (double yolked or poor shells) (McDaniel et al., 1981).

5.3.7 Correlations

Table 5-5 shows the correlation data for rearing traits that were measured at hatch, 9 and 19 wk of age. In general, hatch traits did not correlate well with any 9 or 19 wk traits. However 9 wk traits did correlate well with 19 wk traits. For example the

correlation between hatch weight and 9 wk weight was (r = 0.10893) and the correlation between 9 wk weight and 19 wk weight was (r = 0.69953). Therefore, less emphasis should be placed on hatch weight and greater emphasis placed on achieving uniform weights at 9 and 19 wk which are in line with the recommended breeder guideline.

Table 5-6 presents the correlations of housing BW and carcass length with traits at 61 wk. There was a significant correlation between 19 wk weight and 61 wk weight (r = 0.30430). Frame size measures at 19 and 61 wk were found to correlate more strongly with each other than did juvenile BW and mature BW (61 wk). There was a strong correlation between LYF number and ovary weight (r = 0.87685) which was expected because LYF compromise the majority of total ovary weight.

5.3.8 Conclusions and Applications

The use of an oviduct eversion test allows for a prediction of lay status in hens which has the potential to make producer culling decisions easier. LOW BW hens were more likely to be out of lay when compared to STD and HIGH BW hens. In Flock 1 nearly 10 % of hens had dropped out of lay by 61wk, while only 5 % of hens in Flock 2 had ceased lay. Correlation between traits at hatch and juvenile measures were low, but 9 wk traits correlated more strongly.

5.4 REFERENCES

Agri Stats, Inc. 2002. Live Production Analysis Manual. Agri Stats, Inc., Fort Wayne, IN.

Anonymous. 2003. Aviagen North America Management Guide. Aviagen North America., Huntsville, AL, USA.

Bartov, I., E, Wax, S. Bornstein. 1994. Attempts to achieve low-weight broiler breeder hens by severe growth depression during various periods up to 6 weeks of age and food allocation below the recommendations thereafter. Br. Poult. Sci. 35:573-584.

Bartov, I., E. Wax. 1998. Lack of effect of body weight of breeder pullets at various ages and the amount of food allocated on their subsequent laying performance. Br. Poult. Sci. 39:418-422.

Bruggeman, V., O. Onagnesan, E. D'Hondt, N. Buys, M. Safi, D. Vanmontfort, L. Berghman, F. Vandesande, and E. Decuypere. 1999. Effects of timing and duration of feed restriction during rearing on reproductive characteristics in broiler breeder females. Poult. Sci. 78:1424-1434.

Dunnington, E. A., and P. B. Siegel. 1996. Long-term divergent selection for eight-week body weight in White Rock chickens. Poult. Sci. 75:1168-1179.

Fatori, T. R., H. R. Wilson, R. H. Harms, F. B. Mather, R. D. Miles, and G. D. Butcher. 1993. Response of broiler breeder females to feed restriction below recommended levels. 3. Characterizing the onset of sexual maturity. Poult. Sci. 63:1222-1228.

Gill, S. P. S, and R. P. Amann. 2002. Does evaluation of one or two ejaculates of rooster semen provide a valid basis for culling inferior males? J. Appl. Poult. Res. 11:275-281.

Grossman, M., T. N. Grossman, and W. J. Koops. 2000. A model for persistency of egg production. Poult. Sci. 79:1715-1724.

Hocking, P. M., D. Waddington, M. A. Walker, and A. B. Gilbert. 1987. Ovarian follicular structure of White Leghorns fed *ad libitum* or restricted to point of lay. Br. Poult. Sci. 28:493-506.

Hocking, P. M., and G. W. Robertson. 2000. Ovarian follicular dynamics in selected and control (relaxed selection) male- and female-lines of broiler breeders fed ad libitum or on restricted allocations of food. Br. Poult. Sci. 41:229-234.

Hundson, H. A, W. M. Britton, G. N. Rowland, and R. J. Buhr. 1993. Histomorphometric bone properties of sexually immature and mature White Leghorn hens with evaluation of fluorochrome injection on egg production traits. Poult. Sci. 72:1537-1547.

Hudson, H. A, J. L. Wilson, G. N. Rowland, R. J. Buhr, W. M. Britton. 1999. Feed restriction affects bone properties of the broiler breeder pullet femur. J. Appl. Poult. Res. 8:400-407.

Hudson, B. P., R. J. Lien, and J. B. Hess. 2000. Effects of early protein intake on development and subsequent egg production of broiler breeder hens. J. Appl. Poult. Res. 9:324-333.

Hudson, B. P., R. J. Lien, J. B. Hess. 2001. Effects of body weight uniformity and pre-peak feeding programs on broiler breeder hen performance. J. Appl. Poult. Res. 10:24-32.

Hudson, B. P., W. A. Dozier, III, J. L. Wilson, J. E. Sander, and T. L. Ward. 2004. Reproductive performance and immune status of caged broiler breeder hens provided diets supplemented with either inorganic or organic sources of zinc from hatching to 65 wk of age. J. Appl. Poult. Res. 13:349-359.

Ingram, D. R., and L. F. Hatten, III, B. N. McPherson. 2001. Effects of initiation age of skip-a-day feed restriction on skeletal development in broiler breeder males. J. Appl. Poult. Res. 10:16-20.

Joseph, N. S., F. E. Robinson, R. A. Renema, and M. J. Zuidhof. 2002. Effects of age at photostimulation on reproductive efficiency in three strains of broiler breeders varying in breast yield. J. Appl. Poult. Res. 11:308-319.

Katanbaf, M. N., E. A. Dunnington, and P. B. Siegel. 1989. Restricted feeding in early and late feathering chickens. 1. Growth and physiological responses. Poult. Sci. 68:344-351.

Leeson, S., and J. D. Summers. 1984. Influence of nutritional modification on skeletal size of Leghorn and broiler breeder pullets. Poult. Sci. 63:1222-1228.

Leeson, S., and J. D. Summers. 1987. Effects of immature body weight on laying performance. Poult. Sci. 66:1924-1928.

Lerner, I. M. 1937. Shank length as a criterion of inherent size. Poult. Sci. 16:213-215.

Lopez, G., and S. Leeson. 1994. Nutrition and broiler breeder performance: A review with emphasis on response to diet protein. J. Appl. Poult. Res. 3:303-311.

McDaniel, G. D., J. Brake, and R. D. Bushong. 1981. Factors affecting broiler breeder performance. 1. Relationship of daily feed intake level to reproductive performance of pullets. Poult. Sci. 60:2395-2400.

North, M. O., 1980. Don't neglect the individual bird. Poult. Dig. 39:502-506.

Reddish, J. M., and M. S. Lilburn. 2004. A comparison of growth and development patterns in diverse genotypes of broilers. 2 Pullet growth. Poult. Sci. 83:1072-1076.

Renema, R. A., F. E. Robinson, M. Newcombe, and R. I. McKay. 1999. Effects of body weight and feed allocation during sexual maturation in broiler breeder hens. 1. Growth and carcass characteristics. Poult. Sci. 78:619-628.

Renema, R. A., and F. E. Robinson. 2004. Defining normal: Comparison of feed restriction and full feeding of female broiler breeders. World's Poult. Sci. J. 60:511-525.

Renema, R. A., F. E. Robinson, R. M. Beliveau, H. C. Davis, and E. A. Lindquist. 2007. Relationships of body weight, feathering, and foot pad condition with reproductive and carcass morphology of end-of-season commercial broiler breeder hens. J. Appl Poult. Res. 16:27-38.

Robinson, F. E., R. T. Hardin, and A. R. Robblee. 1990. Reproductive senescence in domestic fowl: effects on egg production, sequence length and inter-sequence pause length. Br. Poult. Sci. 38:871-879.

Robinson, F. E., and N. A. Robinson. 1991. Reproductive performance, growth and body composition of broiler breeder hens differing in body weight at 21 weeks of age. Can. J. Anim. Sci. 71:1233-1239.

Robinson, F. E., J. L. Wilson, M. W. Yu, G. M. Fasenko, and R. T. Hardin. 1993. The relationship between body weight and reproductive efficiency in meat-type chickens. Poult. Sci. 72:912-922.

Robinson, F. E., N. A. Robinson, and R. T. Hardin. 1995. The effects of 20 week body weight and feed allocation during early lay on female broiler breeders. J. Appl. Poult. Res. 4:203-210.

Robinson, F. E., T. A. Wautier, R. T. Hardin, N. A. Robinson, J. L. Wilson, M. Newcombe, and R. I. McKay. 1996. Effects of age at photostimulation on reproductive efficiency and carcass characteristics. 1. Broiler breeder hens. Can. J. Anim. Sci. 76:275-282.

Satterlee, D. G., R. H. Marin. 2004. Pubic spread development and first egg lay in Japanese Quail. J. Appl. Poult. Res. 13:207-212.

Sun, J., C. N. Coon. 2005. The effects of body weight, dietary fat, and feed withdrawal rate on the performance of broiler breeders. J. Appl. Poult. Res. 14:728-739.

Wilson, H. R., D. R. Ingram, F. B. Mather, and R. H. Harms. 1989. Effect of daily restriction and age at initiation of skip-a-day program for young broiler breeders. Poult. Sci. 68:1442-1446.

Wolanski, N. J., R. A. Renema, F.E. Robinson, V. L. Carney, and B. I. Fancher. 2006. Relationship between chick conformation and quality measures with early growth traits in males of eight selected pure or commercial broiler breeder strains. Poult. Sci. 85:1490-1497.

Yu, M. W., F. E. Robinson, and A. R. Robblee. 1992. Effect of feed allowance during rearing and breeding on female broiler breeders. 1. Growth and carcass characteristics. Poult. Sci. 71:1739-1749.

Yuan, T., R. J. Lien, and G. R. McDaniel. 1994. Effects of increased rearing period body weights and early photostimulation on broiler breeder egg production. Poult. Sci. 73:792-800.

TABLE 5-1. Pullet BW and bone growth for two broiler breeder flocks from hatch to 19 wk of age

Bird age	Parameter	Flock 1	Flock 2	SEM
Hatch	Weight (g)	38.38[b]	39.70[a]	0.02
	CV of wt[1] (%)	7.67	8.27	
	Body length (mm)[2]	178.1[b]	180.1[a]	0.03
	Shank length (mm)[3]	28.64[b]	28.81[a]	0.04
9 wk	BW (g)	1081.4[a]	928.6[b]	5.49
	CV of BW (%)[1]	13.88	14.58	
	Shank length (mm)[3]	92.16[a]	87.47[b]	0.17
	Keel length (mm)[4]	113.05[a]	104.81[b]	0.32
19 wk	BW (g)	2214.3[a]	1820.8[b]	9.72
	CV of BW (%)[1]	10.95	13.76	
	Shank length (mm)[3]	107.81[a]	100.71[b]	0.26
	Keel length (mm)[4]	153.51[a]	140.85[b]	0.35

[a-b]Means within a column with different superscripts differ significantly ($P<0.05$).
[1]CV was calculated to measure the spread of BW around the mean.
[2]Measured from tip of bird's beak to the end of the middle toe (not including the nail).
[3]Measured from the top of the hock joint to the bottom of the footpad.
[4]Measured from the hypocleido-clavical joint to the caudal end of the sternum.

TABLE 5-2. Egg production and mortality values for Flock 1 and Flock 2 with reference to the Ross 308 management guide to 61 wk

Parameter	Flock 1	Flock 2	308 Management Guide
Age at 5 % production (wk)	24.5	25.5	25.0
Age at peak lay (wk)	31.0	32.0	31.0
Peak lay (%)	83.4	79.6	84.1
Hen day egg production at 61 wk (%)	48.3	53.9	47.2
Total eggs per hen-housed	161.5	144.7	155.6
Hen mortality (%)	12.8	9.9	14.6[2]

[1] Ross Management Guide 2006, Aviagen North America, Huntsville Alabama.
[2] Mortality was reported to 65 wk in the management guide.

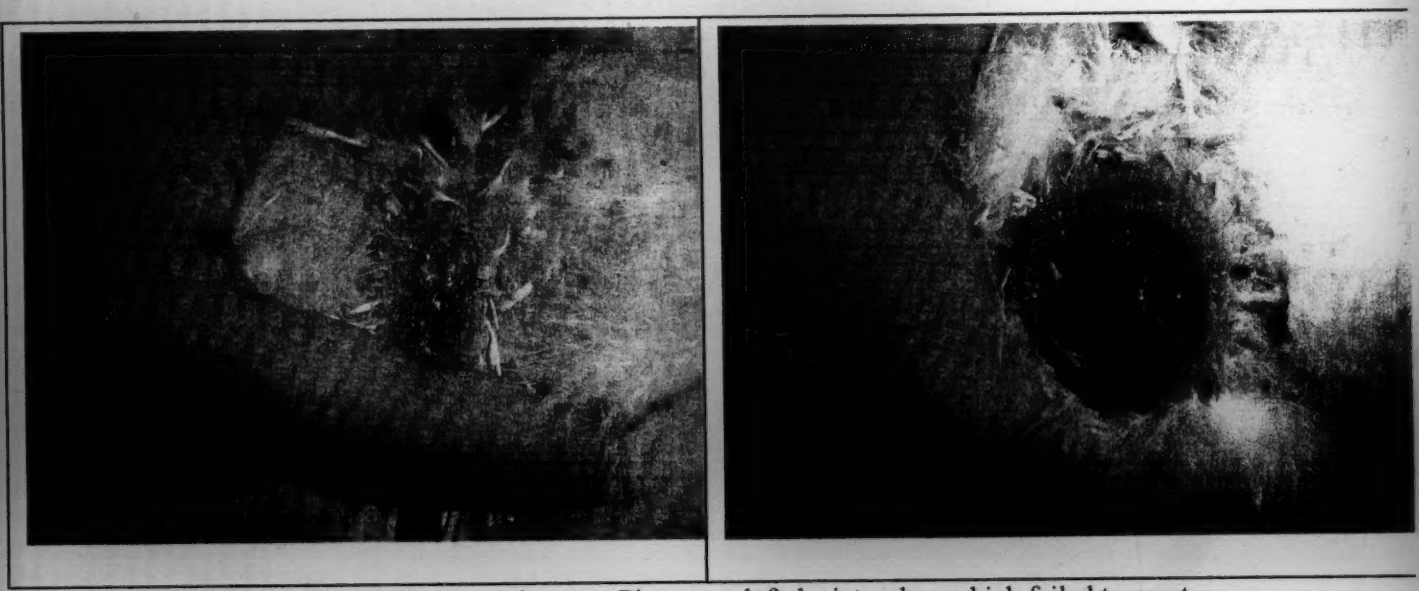

FIGURE 5-1. Oviduct eversion test; Picture on left depicts a hen which failed to evert her oviduct (predicted as out of lay). Picture on right depicts a hen which has everted her oviduct (predicted as in lay).

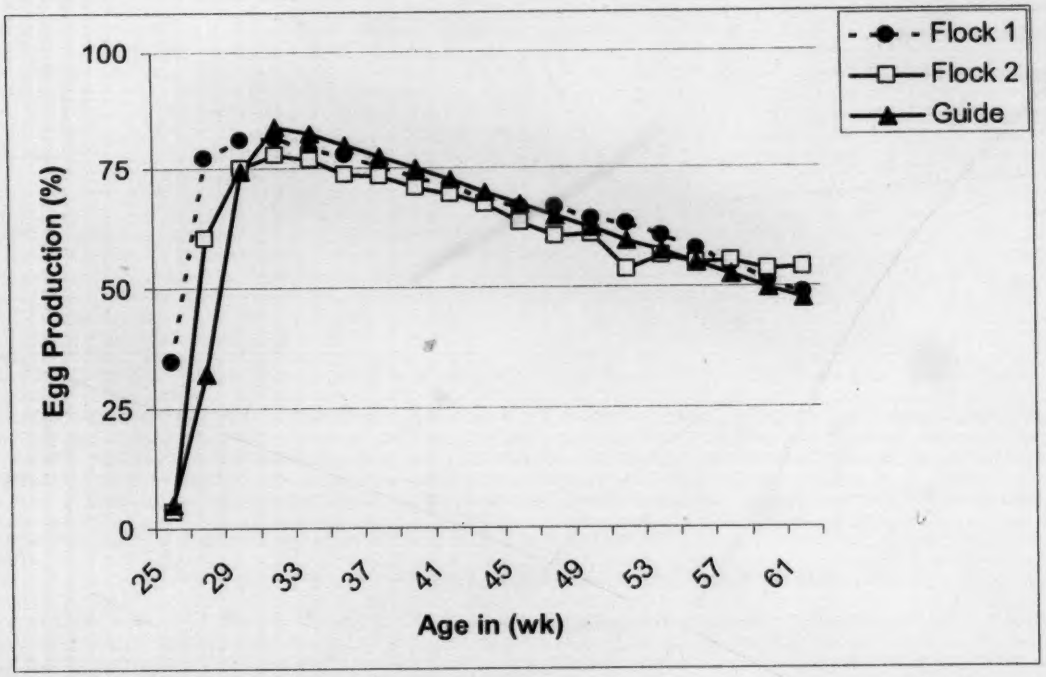

FIGURE 5-2. Egg production curves of Flock 1 and Flock 2 as compared to the Ross management guide for a 308 hen.

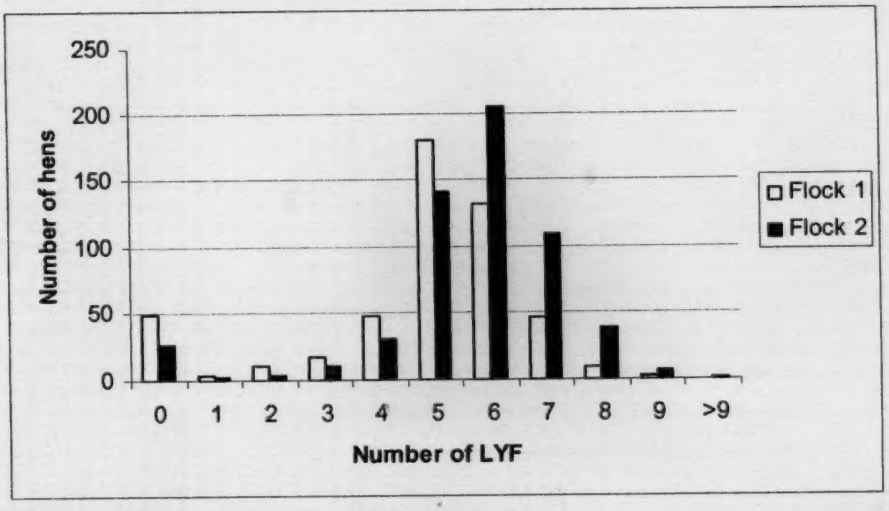

FIGURE 5-3. Distribution of large yellow follicle (LYF) numbers for hens from Flock 1 (n = 497) and Flock 2 (n = 564).

TABLE 5-3. Body weight, carcass morphometrics and reproductive characteristics of broiler breeder hens from two flocks sorted into three BW groupings at 61 wk of age

Source	n	BW (g)	Shank length (mm)[2]	Keel length (mm)[3]	Ovary wt (g)	Fat pad wt (g)	LYF (#)
Flock							
#1	497	3949	111.26[a]	165.40[a]	60.50[b]	136.8	4.70[b]
#2	564	3968	110.68[b]	160.34[b]	67.29[a]	137.6	5.60[a]
SEM		9.9	0.18	0.32	1.00	2.3	0.08
Flock 1 BW Category							
LOW	139	3433[c]	109.86[c]	162.79[c]	50.01[b]	84.0[c]	3.98[b]
STD	198	3959[b]	110.78[b]	164.68[b]	65.39[a]	139.8[b]	5.13[a]
HIGH	155	4456[a]	113.14[a]	168.73[a]	66.17[a]	186.7[a]	5.00[a]
SEM		17.5	0.34	0.59	1.86	4.3	0.15
Flock 2 BW Category							
LOW	149	3490[c]	108.41[c]	156.66[c]	60.40[c]	94.0[c]	5.21[b]
STD	268	3966[b]	110.82[b]	160.41[b]	68.98[b]	140.7[b]	5.73[a]
HIGH	145	4448[a]	112.80[a]	163.95[a]	72.47[a]	178.2[a]	5.87[a]
SEM		18.2	0.33	0.57	1.82	4.1	0.15
Source of variation							
Flock		0.1754	0.0199	<0.0001	<0.0001	0.7935	<0.0001
BW Category		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Flock X BW Category		0.1676	0.0424	0.1973	0.1197	0.0806	0.0682

[a-c]Means within a column with different superscripts differ significantly ($P \leq 0.05$).
[1]Divided into uniform weight classes around the mean flock BW. LOW = low,<3,750 g; STD = standard, 3,750 to 4,180 g; HIGH = high, > 4180 g.
[2] Measured from the top of the hock joint to the bottom of the foot pad.
[3] Measured from the hypocleido-clavical joint to the caudal end of the sternum.

TABLE 5-4. Reproductive condition of hens from two flocks sorted into three BW groupings at 61 wk of age

Source	n	Predicted non laying (#)[2]	Predicted non laying (%)[2]	Reproductive disorders (%)[3]	Birds out of lay (#)[3]	Birds out of lay (%)[3]
Flock						
#1	497	43	8.65	9.86[b]	48[a]	9.76[a]
#2	564	21	3.72	14.01[a]	26[b]	4.63[b]
SEM		0.22	0.22	0.01	0.20	0.01
Flock 1BW Category[1]						
LOW	139	35[a]	25.2	8.63	33[a]	23.74[a]
STD	198	4[b]	2.02	7.46	6[b]	3.03[b]
HIGH	155	4[b]	2.58	14.01	9[b]	5.81[b]
SEM		0.51	0.51	0.03	0.41	0.04
Flock 2BW Category[1]						
LOW	149	15[a]	10.1	15.44	12[a]	8.05[a]
STD	268	4[b]	1.49	12.96	11[a]	4.10[b]
HIGH	145	2[b]	1.38	14.48	3[b]	2.07[b]
SEM		0.50	0.50	0.03	0.58	0.02
Source of variation						
Flock		0.0850	0.0850	0.0281	0.0286	0.0286
BW Category		<0.0001	<0.0001	0.1965	<0.0001	<0.0001
BW Category X Flock		0.5601	0.5601	0.3505	0.0388	0.0388

[a-c]Means within a column with different superscripts differ significantly ($P \leq 0.05$).
[1]Divided into uniform weight classes around the mean flock BW. LOW = low,<3,750 g; STD = standard, 3,750 to 4,180 g; HIGH = high, > 4180 g.
[2] Laying status was predicted using the oviduct eversion test.
[3] Chi square analysis was done on reproductive disorders and the # of birds out of lay

TABLE 5-5. Correlation coefficients (and P-values) of hatch traits and early growth measurements in juvenile female broiler breeders

	Hatch body length	Hatch shank length	9 wk BW	9 wk shank length	9 wk keel length	19 wk BW	19 wk shank length	19 wk keel length
Hatch wt	0.21875	0.28853	0.10893	0.08827	0.02123	0.02526	0.02753	0.02940
	(0.0001)	(0.0001)	(0.0001)	(0.0011)	(0.4332)	(0.3638)	(0.3223)	(0.2907)
Hatch body length		0.32864	0.01842	0.05988	0.00596	0.00364	0.03797	0.03250
		(0.0001)	(0.4965)	(0.0270)	(0.8259)	(0.8958)	(0.1722)	(0.2427)
Hatch shank length			0.04552	0.13066	0.02801	0.01009	0.07407	0.00286
			(0.0927)	(0.0001)	(0.3010)	(0.7168)	(0.0077)	(0.9181)
9 wk BW				0.87803	0.84422	0.79492	0.55174	0.69953
				(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)
9 wk shank length					0.82609	0.70951	0.63698	0.67717
					(0.0001)	(0.0001)	(0.0001)	(0.0001)
9 wk keel length						0.73126	0.59533	0.78766
						(0.0001)	(0.0001)	(0.0001)
19 wk BW							0.68459	0.85124
							(0.0001)	(0.0001)
19 wk shank length								0.74134
								(0.0001)

TABLE 5-6. Correlation coefficients (and P-values) of 19 wk weight and 61 week traits in female broiler breeders

	19 wk shank length	19 wk keel length	61 wk BW	61 wk shank length	61 wk keel length	Ovary wt	LYF #
19 wk BW	0.68459	0.85124	0.29194	0.30430	0.36791	0.03028	0.10458
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.3345)	(0.0008)
19 wk shank length		0.74134	0.25526	0.47944	0.47927	0.02632	0.11510
		(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.4015)	(0.0002)
19 wk keel length			0.24031	0.31461	0.52328	0.05373	0.13239
			(0.0001)	(0.0001)	(0.0001)	(0.0867)	(0.0001)
61 wk BW				0.33986	0.36241	0.30201	0.24852
				(0.0001)	(0.0001)	(0.0001)	(0.0001)
61 wk shank length					0.30280	0.04943	0.00139
					(0.0001)	(0.1089)	(0.9640)
61 wk keel length						0.06306	0.10020
						(0.0420)	(0.0012)
Ovary wt							0.87685
							(0.0001)

6.0 GENERAL DISCUSSION

In Canada, hatching egg producers provide fertile eggs to hatcheries which then supply broiler producers with meat-type chickens. There are many challenges and potential conflicts which arise throughout this value chain. Hatching egg producers must feed restrict parent stock to ensure adequate egg production and fertility for the life of a flock. However, even with feed restriction of birds, there is a natural decline in reproductive efficiency as breeding stocks age. Identification of birds which were reproductively unfit would enable hatching egg producers to make better culling decisions and potentially keep flocks in production longer. By increasing the age at processing for spent fowl hatching egg producers could supply a greater number of chicks/hen housed to the broiler growers. Broiler producers receive chicks from a commercial hatchery and must try to minimize the level of chick mortality during the brooding and grow out phase in order to maximize profits. In cases where brooding mortality is high, the hatchery might be blamed for poor chick quality. It is important to note that chick livability can be impacted at all stages of the hatching-egg- and broiler production chain. Therefore, this thesis explored chick quality (Chapters 2 and 3) to better understand what chick traits at hatch were important. In commercial broiler breeder flocks, growth and reproductive aging of both male and female broiler breeders was studied from hatch until depopulation (61 wk) (Chapters 4 and 5).

Egg traits such as yolk weight, albumen weight and shell characteristics were influenced by the genetic strain of the hen. Strain also impacted the hatch traits of chicks investigated in both chapters. Chick weight was significantly influenced by strain however, yolk utilization across the strains surveyed was impacted to a greater degree. A

chick abdomen score was developed to estimate residual yolk content of live chicks and this score correlated with the weight of residual yolk obtained at dissection ($r = 0.50$). In general, pure line strains had more residual yolk at the time of hatch (5.5 g) when compared to commercially available crosses (3.7 g). All of the eggs used in these trials were incubated under commercial specifications for temperature and humidity which may have favored the commercial strains. Therefore, incubation conditions may need to be modified when hatching chick with differing genetic backgrounds. Chick traits at hatch, consistently showed that hatch weight was a poor indicator of growth potential as the correlation between hatch weight and 14 d BW were low ($r = 0.35$). Chick growth rate and breast muscle development were significantly influenced by strain. The coefficient of variation for residual yolk weight was extremely high at hatch (43 %) suggesting that many factors impact chick yolk utilization. There is a tremendous amount of variation in chick traits and chick growth rates which can be utilized by primary breeders to develop new commercial crosses in the future.

Broiler breeder males are heavily feed restricted during rearing and production to improve fertility and livability. Male BW is responsive to the amount of feed allocated and the male's ability to obtain feed. Juvenile BW at 18 wk was found to poorly correlate with BW at 61 wk ($r = 0.17$), suggesting that numerous factors within the breeder barn modify mature male weight. Male mortality continues to be a problem in the breeder industry. Mortality during rearing (0 – 18 wk) was 2.8 %, however mortality during lay was high resulting in a mortality rate of 38.6 % by 61 wk. The primary cause of death was male aggression/septicemia which was determined by post-mortem examination. Approximately 40 % of postmortem cases had males with regressed testes

(>15 g) whereas in males which survived to 61 wk only 10 % had undergone testicular regression. Male mortality will become more of an issue as animal welfare groups target the poultry industry therefore, the primary breeders must make efforts to improve male survival.

As broiler breeder hens age, reproductive efficiency declines which requires flocks to be processed. In some flocks, egg production will decline rapidly following peak lay while other flocks have a better persistency of lay. In Chapter 5, two commercial Ross 308 flocks were compared for growth profile, egg production, and reproductive condition at 61 wk. Flock 2 experienced a coccidiosis challenge which resulted in an observable reduction of BW, shank length, and keel length at 9 and 19 wk of age. However, by 61 wk, BW between the two flocks was comparable and the magnitude of difference in skeletal measures was reduced. Flock 1 had better egg production for the majority of the lay period, however for the last 5 wk of production Flock 2 had better production. In this study, an oviduct eversion test was designed to allow the prediction of laying status of hens. This test was effective in predicting that a higher percentage of hens in Flock 1 had ceased egg production. It was noted that a higher proportion of LOW weight hens had gone out of production as compared to birds which had either a standard (STD) or HIGH BW profile (24 %, 3 %, and 6 % respectively). In some flocks, 20 – 30 % of hens may be out of laying condition by the time of flock dispersal (<60 wk). The use of an oviduct eversion test will allow producers to cull out hens which are out of lay and simply consuming feed.